NASA CR-132305

PROTOTYPE PARTIAL ONE-THIRD OCTAVE BAND SPECTRUM ANALYZER FOR ACOUSTIC, VIBRATION AND OTHER WIDEBAND DATA FOR FLIGHT APPLICATIONS

October 1973

Prepared under Contract NAS1-11823

Prepared by:

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

Prepared for:

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365

NASA CR-132305

PROTOTYPE PARTIAL ONE-THIRD OCTAVE BAND SPECTRUM ANALYZER FOR ACOUSTIC, VIBRATION AND OTHER WIDEBAND DATA FOR FLIGHT APPLICATIONS

October 1973

Prepared under Contract NAS1-11823

Prepared by:

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

Prepared for:

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365

FOREWORD

The equipment reported herein was constructed by Bolt Beranek and Newman Inc. under Contract NAS1-11823. Acknowledgement is given to Byron E. Blanchard of BBN, who was responsible for the circuit design, and to Mr. Alfred Beswick of Langley Research Center who provided valuable assistance during the performance of the contract.

ABSTRACT

The design refinement of a compact frequency analyzer for measurement and analysis on board flight vehicles is discussed.

The analyzer has been constructed in a partial one-third octave band configuration with six filters and detectors spaced by the $\sqrt{10}$ from 316 Hz to 100,000 Hz and a broadband detector channel. The analyzer has been tested over a temperature range of 40 to 120°F at a pressure of one atmosphere, and at a temperature of 75°F at an absolute pressure of 1×10^{-6} torr, and has demonstrated at least 60 dB of dynamic range.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES *(cont.)*

LIST OF FIGURES *(cont.)*

1. INTRODUCTION

Acoustic and vibration measurements made on flight vehicles often require wideband data. Such data are usually telemetered or stored on-board for frequency analysis at a later time. However, telemetry and magnetic tape data bandwidths are limited, thus imposing restrictions on the amount of wideband data that can be collected on any one flight. Hence, techniques for obtaining the essential information content of wideband data and converting it into more typical narrowband data that can be commutated, transmitted, or stored can be very useful.

In this program, a partial one-third-octave band analyzer for frequency bands between 316 Hz and 100 kHz was designed and built, using active filters for the lower frequencies (316 Hz, 1000 Hz, 3160 Hz) and passive filters for the higher frequencies (10 kHz, 31.6 kHz, 100 kHz). The analyzer performs a frequency analysis of the wideband data on-board the vehicle. Its output is a slowly-varying signal that is compatible with the narrower bandwidths of standard equipment, but which still contains the essential frequency-amplitude information of the original wideband data.

To perform such a spectrum analysis effectively, an analyzer must be capable of handling a very wide range of input signals. The designs utilized in this analyzer can accept signals with a range of amplitudes varying by a factor greater than 1000 (i.e., 60 dB) and compress this information into 12 dB/volt at the output (a range of five volts).

The spectrum analyzer and its circuitry are described in detail in Sec. 2 of this report. Section 3 presents the results of temperature and pressure testing of each of six filters and one broadband detector and associated circuitries which comprise

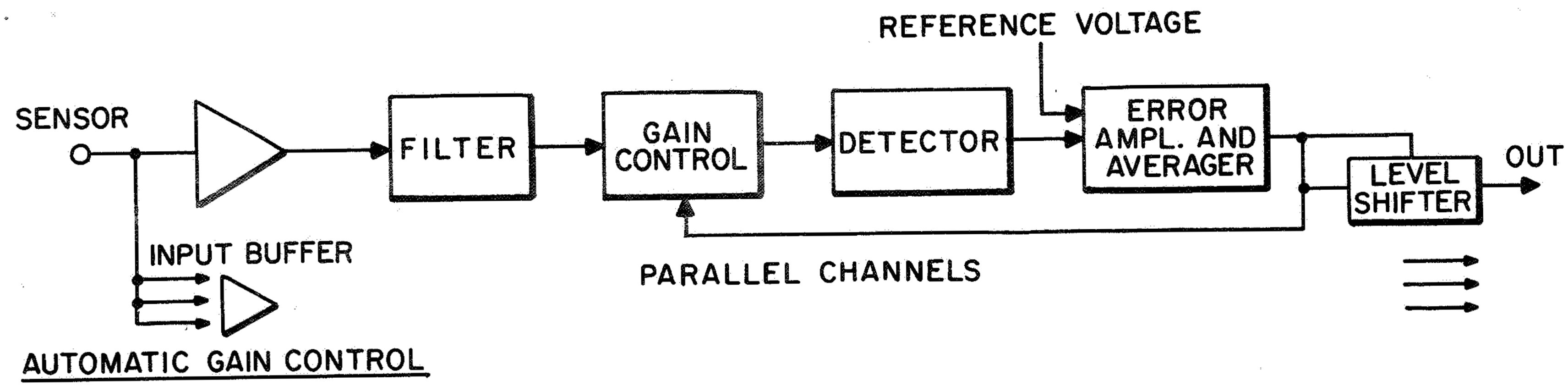


FIG. 1. ANALYZER CONFIGURATION

the partial analyzer. The tests determined the frequency-amplitude response characteristics at temperatures of 40°F, 70°F, and 120°F at pressures of one atmosphere and 1×10^{-6} torr.

2. TECHNICAL DESCRIPTION

The frequency range of interest for the analyzer was specified to extend from 316 Hz to 100 kHz and the amplitude levels of signals within this range were specified to permit a variation of 60 dB. It was necessary to evaluate a prototype spectrum analyzer design and investigate whether different technologies and/or recent technological advances currently available are better suited for the partial analyzer. Design considerations including size, weight, and power consumption were weighed against potential performance gains in determining the final design configuration.

A block diagram of the partial analyzer is shown in Fig. 2 and each of the blocks is described below.

2.1 Buffer Amplifier

A unity-gain buffer amplifier in each filter section provides an impedance matching function from the high output impedance of the transducers to the relatively low impedance levels required by the filters. The buffer amplifier is internally connected to operate as a voltage follower.

2.2 Filters

All of the filters are designed to meet or exceed the American Standards Association Specification S1.11-1966 One-Third Octave Band Filter, Class II. A copy of this specification is appended to the report.

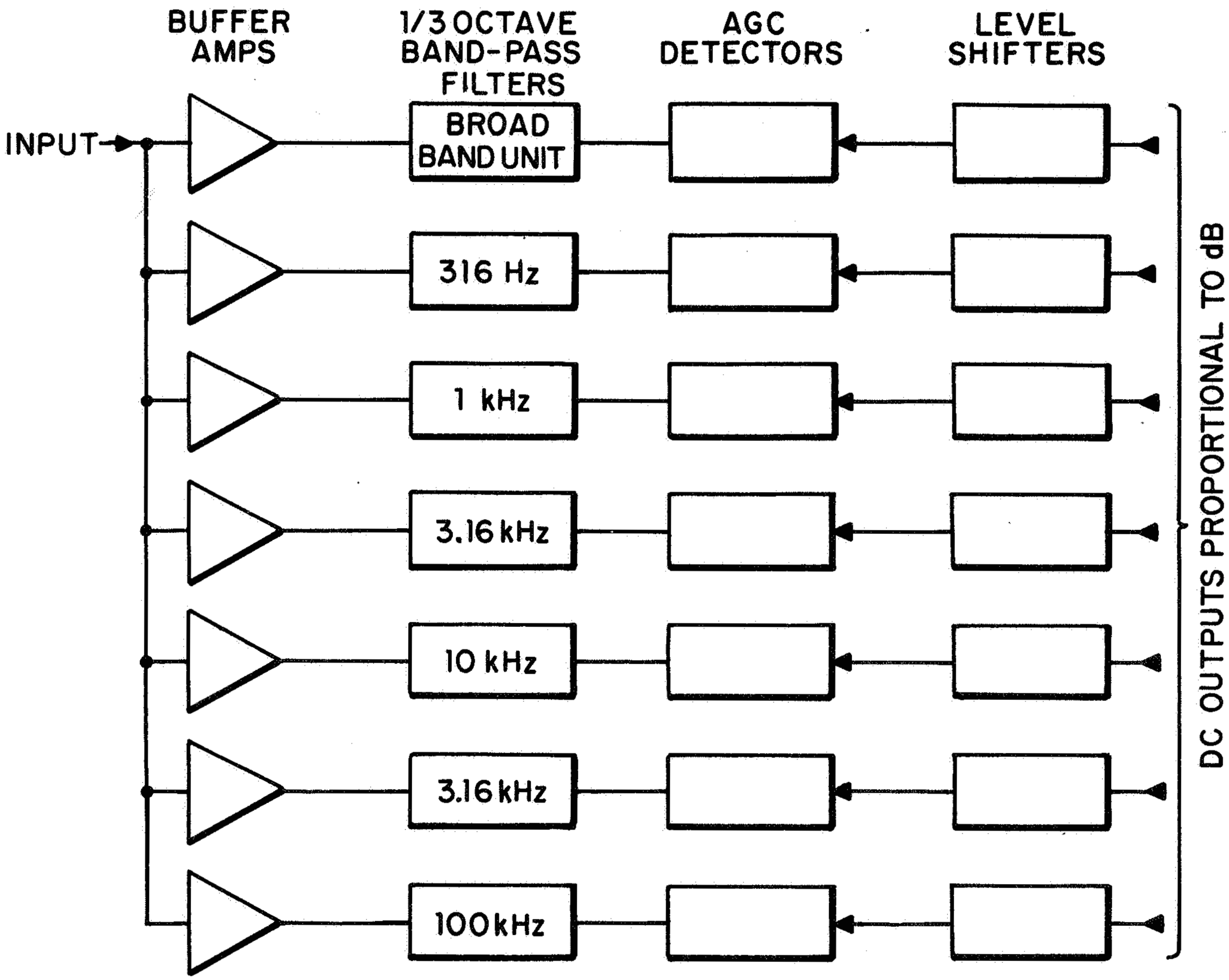
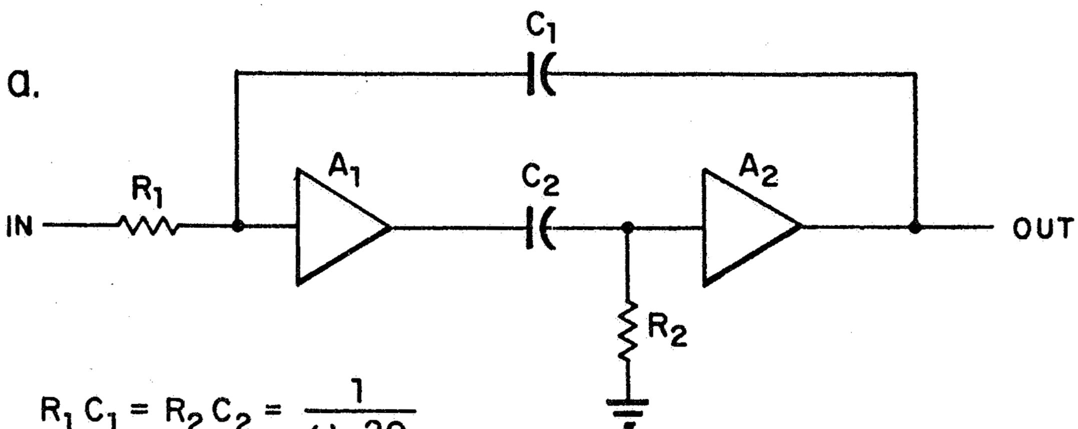


FIG. 2. BLOCK DIAGRAM OF PARTIAL ANALYZER

2.3 Low-Frequency Active Filters

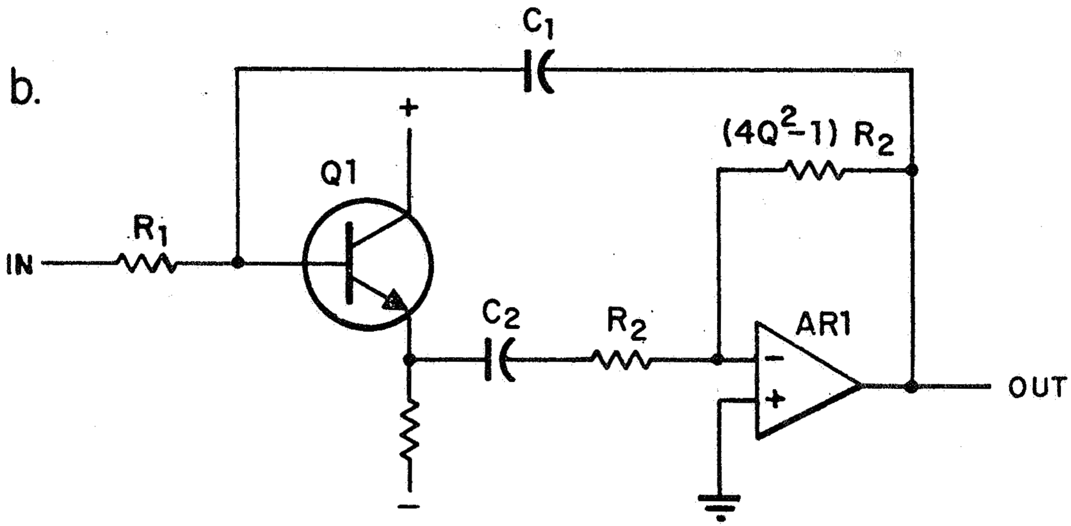
Two versions of a negative feedback resonator circuit with low "Q" sensitivity are used for the low frequency filters. The general form of the circuit for the 316 Hz and 1000 Hz filters and its basic design are shown in Fig. 3. In Fig. 4 the circuit used for the 3160 Hz filter and its basic design equations are shown. The amplifier gain required is proportional to the square of Q, so the maximum Q available is severely limited by the gain. The amplifier feedback circuit is of high-pass form so compensation is required for 100% feedback at low frequencies.

The combination of high gain and drastic compensation limits the usefulness of either configuration to low frequencies. However, within its range (up to 5 or 10 kHz) either circuit has several advantages: total insensitivity of Q to small component value changes, low sensitivity of Q to amplifier gain. The circuit shown in Fig. 3 uses an emitter follower configuration with unity gain for the first amplifier and one-half of a dual operational amplifier for the second amplifier. The circuit shown in Fig. 4 dispenses with the emitter follower while retaining the second amplifier. In either case, each complete filter consists of two sections, tuned to 0.92 and 1.08 times the nominal center frequency, with Q of 6.1; these values provide a maximally-flat one-third octave band filter, i.e., 26% bandwidth.



$$R_1 C_1 = R_2 C_2 = \frac{1}{\omega_0 2Q}$$

$$-A_1 A_2 = 4Q^2 - 1$$



$$A_1 = 1$$

$$A_2 = -(4Q^2 - 1)$$

FIG. 3. FORM AND DESIGN EQUATIONS FOR NEGATIVE FEEDBACK Q INSENSITIVE RESONATOR (316 Hz AND 1000 Hz FILTERS)

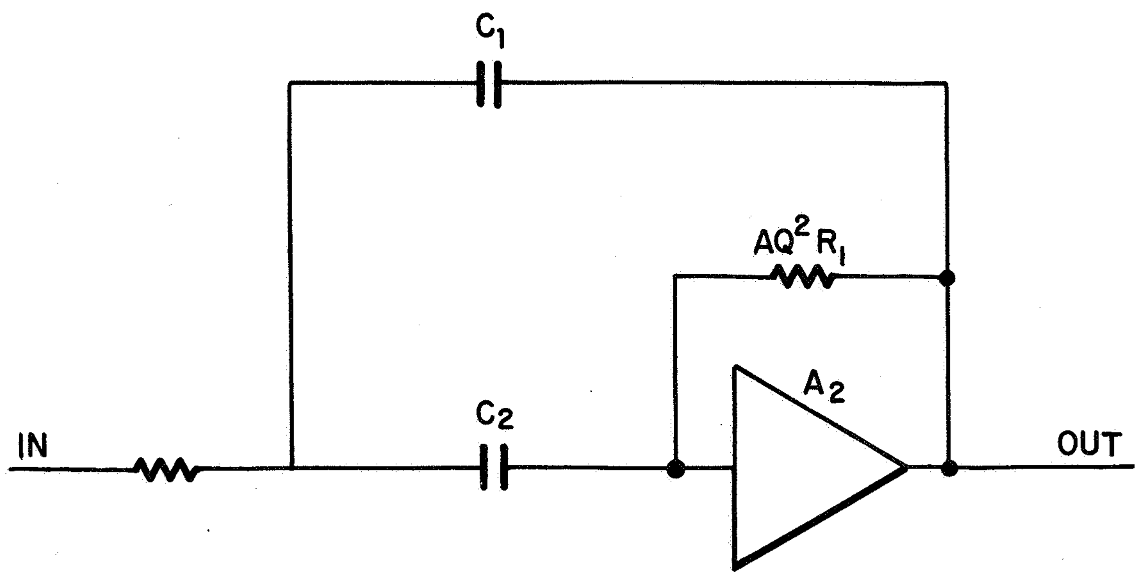


FIG. 4. FORM AND DESIGN EQUATIONS FOR NEGATIVE FEEDBACK Q INSENSITIVE RESONATOR (3.16 kHz FILTER)

2.4 High-Frequency Passive Filters

The filters with nominal center frequencies of 10 kHz, 31.6 kHz, and 100 kHz were built using the passive circuitry shown in Fig. 5. The resistors, capacitors, and inductors used are of sufficient quality to be stable over the temperature range and require a minimum of compensation for internal losses. The passive filters are designed for a 23% bandwidth.

2.5 Detectors

The basic detector, which in simplest form is just a diode rectifier, is crucial to the performance of any analyzer configuration. To reduce the errors due to the offset biasing voltage required by the diode, an operational amplifier is commonly used. In this circuit the diode is connected inside the feedback loop of the operational amplifier as shown in Fig. 6. The open loop gain of the amplifier reduces the diode voltage drop.

However, as frequency increases, the finite slewing rate of the amplifier output and the necessity for the amplifier output voltage to traverse two diode drops for each polarity reversal of the signal cause increasingly large errors in the circiut of Fig. 6. The frequency response performance of this circuit is strongly dependent on signal amplitude level and is not adequate at any signal level above about 80 kHz. Increasing the amplifier compensation to achieve a faster slewing rate improves the frequency response performance. However, it is still strongly dependent on signal amplitude level.

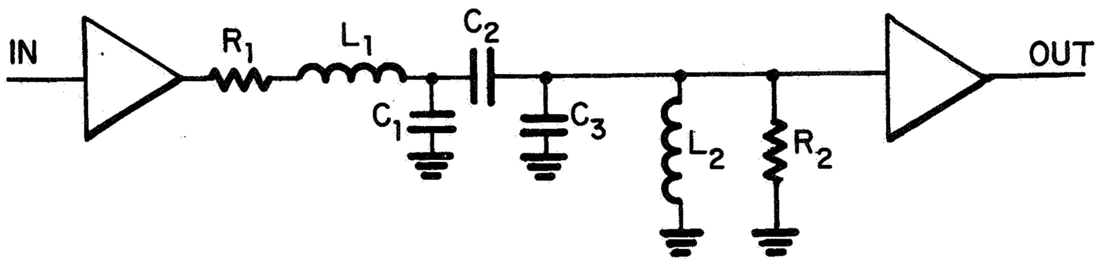


FIG. 5. FORM AND DESIGN EQUATIONS FOR HIGH FREQUENCY PASSIVE FILTERS

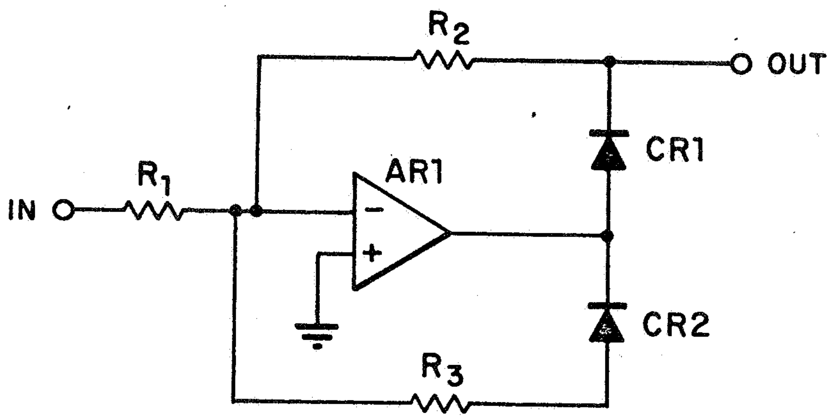


FIG. 6. OPERATIONAL RECTIFIER

The frequency response performance is extended to meet or exceed the required specifications at all signal levels by adding a separate grounded-base voltage-to-current amplifier after the operational amplifier. However, this circuit is not acceptable because of its size, weight, and power consumption. Instead, an operational transconductance amplifier (RCA CA 3080) is used and performs adequately with the detector signal level held constant by the AGC circuit described later. The frequency response performance curves for the detector using a CA 3080 are shown in Fig. 7.

2.6 Gain Control Block

The gain control is used in the AGC circuit configuration to keep the detector signal-level constant and to provide the logarithmic function for the system. A schematic of the gain control is shown in Fig. 8. Basically, the AGC circuitry derives a control voltage related to the overall amplitude of the input signal and uses it to vary the gain of the amplifier so that the signal level applied to the detector circuit remains essentially constant in amplitude. The derived voltage is, although later scaled and level shifted, essentially the output information of an analyzer channel.

The operation of the circuit can be explained as follows. The input signal is fed through input capacitor C_1 and resistor R_1 to the gate of the FET follower Q_{1A} and then to the operational amplifier AR1. The use of the FET in front of AR1 is to reduce the input bias current of AR1 which flows through the current splitter and appears at the output as apparent control

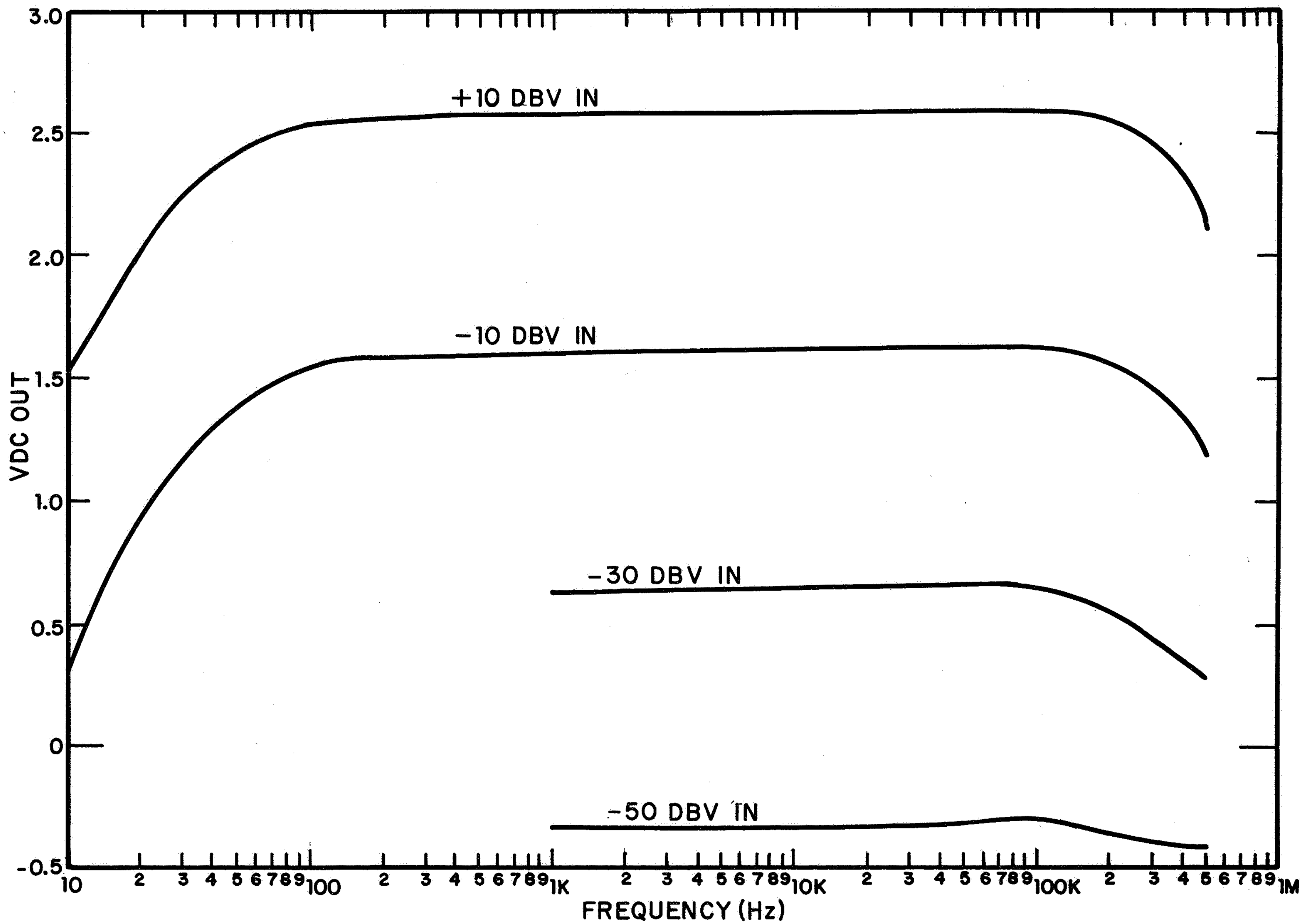


FIG. 7. AGC DETECTOR RESPONSE CURVES WITH CA 3080

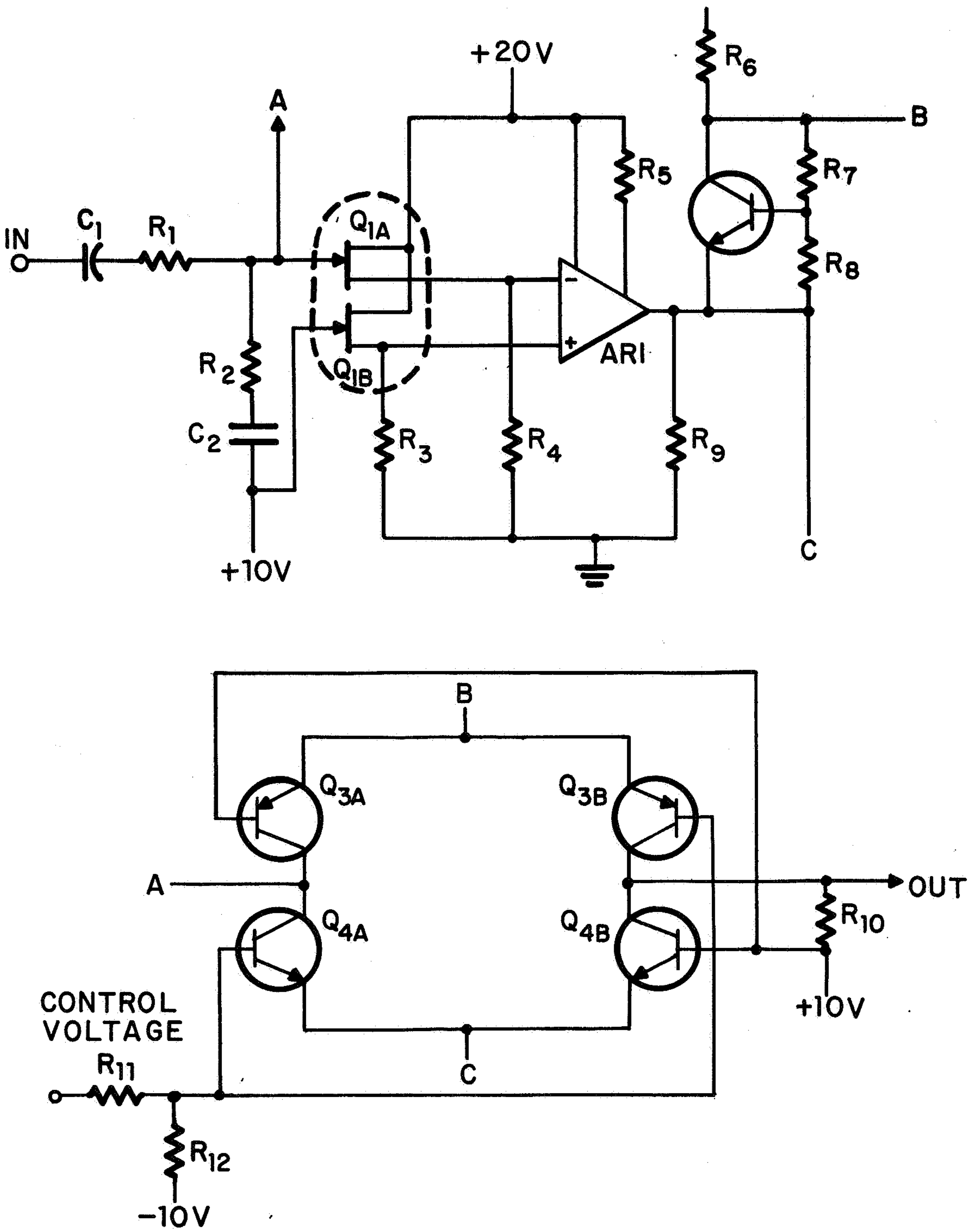


FIG. 8. GAIN CONTROL BLOCK

voltage feedthrough. The output of AR1 drives the current splitter transistors Q_3 and Q_4 which are driven by Class AB with the bias level determined by Q_2, along with R_7 and R_8 making up a "variable diode". Feedback current, through the transistors Q_{3A} and Q_{4A}, keeps the AC voltage at the gate of Q_{1A} small and the AC current in Q_{3A} nearly equal to the current in R_1. Thus, the AC collector current of Q_{3A} is established and controlled by the input voltage level. Q_{3A} and Q_{3B} are a matched pair of transistors connected as a current splitter. The base voltage gain of the circuit is R_{10}/R_1.

When the base voltages of Q_{3A} and Q_{3B} are unequal, the ratio of their collector currents is exponentially related to the interbase voltage

$$\frac{I_2}{I_1} = \exp\left(\frac{qV}{kT}\right)$$

where I_2 and I_1 are the respective collector currents, q is the charge of an electron, V is the interbase voltage, k is Boltzmann's constant, and T is the absolute temperature. The temperature dependence is compensated for by a temperature-dependent voltage divider consisting of resistors R_{11} and R_{12}; R_{12} has a positive temperature coefficient whose value is proportional to the absolute temperature. Thus it is shown in Fig. 8 that transistors Q_{3A} and Q_{3B} in the circuit form a precise AC gain control with an exponential, or logarithmic, operating characteristic. Transistors Q_{4A} and Q_{4B} keep the DC operating point of the gain control from shifting as the signal amplitude level and the circuit gain change, i.e., they keep the circuit symmetrical under all operating conditions.

2.7 Error Integrator

A schematic of the error integrator is shown in Fig. 9. In operation, the difference between the input through R_1 and the reference current through R_2 is integrated and used to control the gain block and drive the level shifter. CR_1 prevents the output of AR_1 swinging more negative than the +10V reference voltage. In the filter channels, AR_1 is one-half of a dual operational amplifier.

2.8 Level Shifter

The output level shifter AR_1 with Q_5 shifts the output voltage to ground as reference, rather than +10V as reference as in all previously described circuits. The level shifter forces the same current to flow in R_1 and R_2 and also keeps the right hand end of R_1 at +10V. Thus the output voltage across R_2 with respect to ground is 5/6 of the voltage across R_1 with respect to +10V. The factor 5/6 comes from the choice of scaling of voltage vs dB; at the output 5V represents 60 dB in order to be compatible with telemetry inputs. The resulting 12 dB/V is inconvient for in-process testing; 10 dB/V is preferred and so is chosen as the internal scaling. In the schematic of the level shifter, Fig. 10, AR_1 is the second half of the dual operational shared with the error integrator.

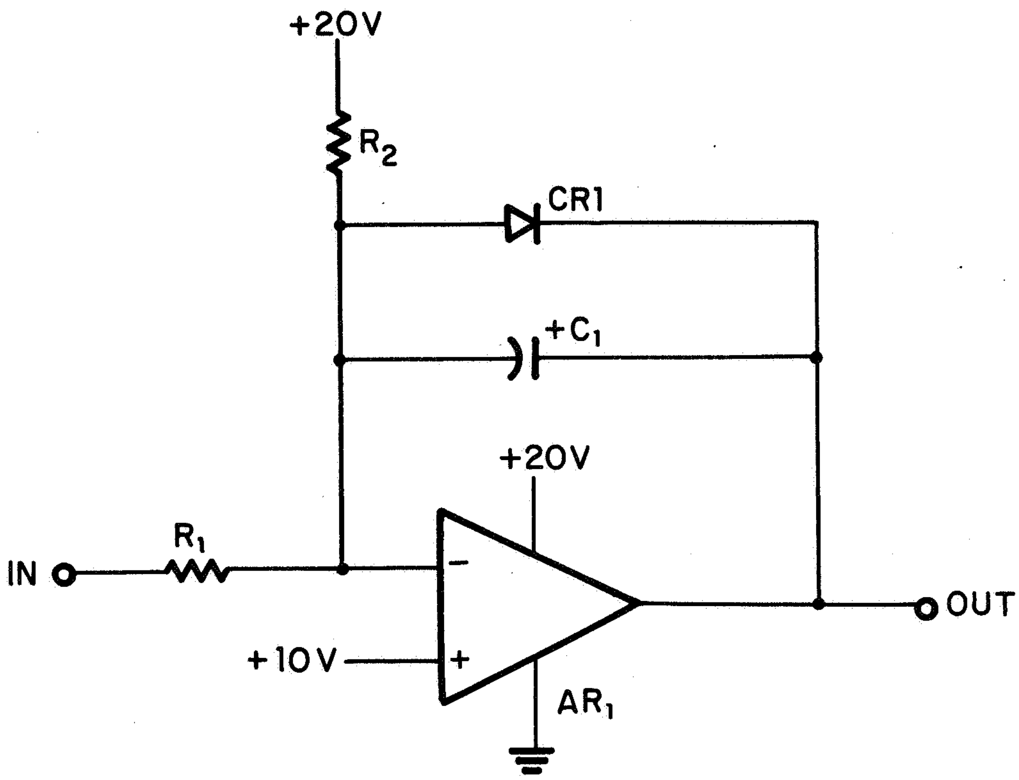


FIG. 9. ERROR INTEGRATOR

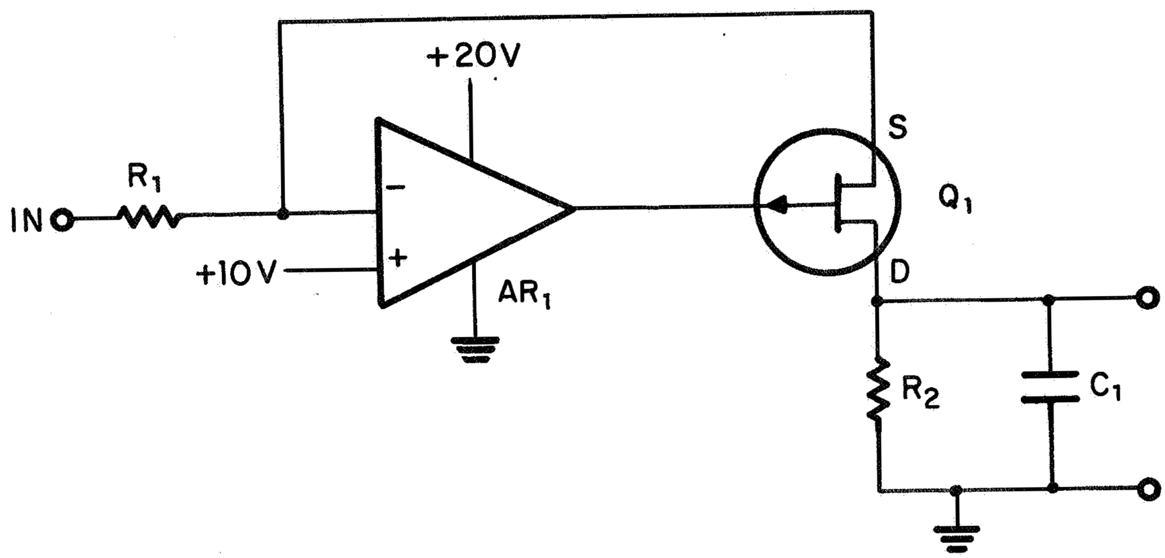


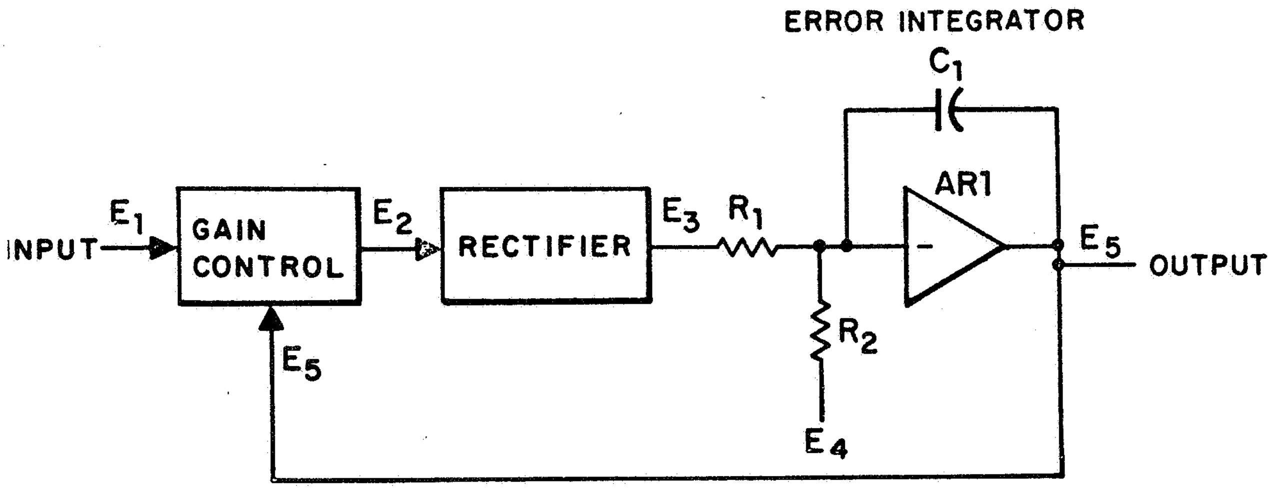
FIG. 10. LEVEL SHIFTER

2.9 AGC Detector

The Automatic Gain Control Detector configuration consists of a gain block, high gain amplifier consisting of one unity gain operational amplifier and one 60 dB operational amplifier, a detector, and an error integrator. The output voltage of the error integrator is used as the AGC Detector system output and since the relationship between the system gain and the control voltage can be made almost exactly logarithmic, output can be given directly in dB. Figure 11 shows the AGC Detector circuit configuration schematically and also shows the differential equation of its response.

2.10 Summary

An analyzer design was completed which met the specified performance requirements of one-third octave band frequency-amplitude analysis from 316 Hz to 100 kHz over a 60 dB dynamic range. Additionally, a wideband detector is included as a separate channel for customer convenience. Test results which demonstrate achievement of the design goals are presented in the next section. The design required active and passive filter circuit configurations to cover the frequency range. An automatic gain control circuit was used to convert the input signal logarithmically and reduce the range requirements on the detectors.



$$E_2 = E_1 \epsilon^{KE_5}$$

$$E_3 = +|E_2|, \quad \text{at AR1 INPUT } \sum I = 0$$

$$\frac{E_3}{R_1} + \frac{E_4}{R_2} + C \frac{d}{dt} E_5 = 0$$

assume $E_1 > 0$

$$\frac{E_1}{R_1} \epsilon^{KE_5} + \frac{E_4}{R_2} + C_1 \frac{d}{dt} E_5 = 0$$

$$\epsilon^{KE_5} = \frac{R_1}{E_1} \left(- \frac{E_4}{R_2} - C_1 \frac{d}{dt} E_5 \right)$$

$$E_5 = \frac{1}{K} \log_\epsilon \left(- \frac{E_4 R_1}{E_1 R_2} - C_1 \frac{d}{dt} E_5 \right)$$

$$t \gg 0, \quad E_5 \cong \frac{1}{K} \log_\epsilon \left(\frac{-E_4 R_1}{E_1 R_2} \right) = \frac{1}{K} \left(-\log_\epsilon E_1 + \log_\epsilon \frac{-E_4 R_1}{R_2} \right)$$

FIG. 11. AGC DETECTOR ANALYSIS

3. TEST RESULTS

A partial analyzer system consisting of six one-third octave band filters and one wideband detector was fabricated and tested according to program specifications. A block diagram of the analyzer is shown in Fig. 2. The set of six filters was selected to cover the frequency range of interest.

Transfer characteristics of the frequency amplitude response of the system are shown in Figs. 12 through 18. These characteristics were plotted at 40°F, 75°F, and 120°F at normal atmospheric pressure. For comparison purposes, the curves are fitted to the data plotted at 75°F only. The ordinate scale is the DC output expressed in dB at the compression factor of 12 dB/volt (i.e., $\Delta 10$ dB = $\Delta 0.833$ V at the output). The data was taken by applying a sine wave signal at the input and recording the output of each channel. The input signal, nominally 0 dBV, was adjusted for 5 V DC out prior to plotting the response for each filter. This procedure is justified. Later we show that the output of each filter is within the limits of the specification.

Figures 19 through 25 present data from tests performed to establish the dynamic range and linearity of each channel over the temperature range at normal atmospheric pressure. Here the input is adjusted exactly re 0 dB/V and the output is then recorded. The information obtained is plotted as an error curve which readily demonstrates that the filter channel complies with linearity and dynamic range requirements. Since the "error" in every case is re the ideal (i.e., 0 dB V in = 5.000 V DC out, -60 dB V in = 0.000 V DC out) one readily accepts that we have justified the procedure previously employed in determining the frequency response amplitude characteristics of the filters.

Successful testing of the analyzer system was concluded by determining that the filters operate correctly at 75°F at an absolute pressure of 1×10^{-6} torr. The results of these pressure tests are shown in Figs. 26 through 39.

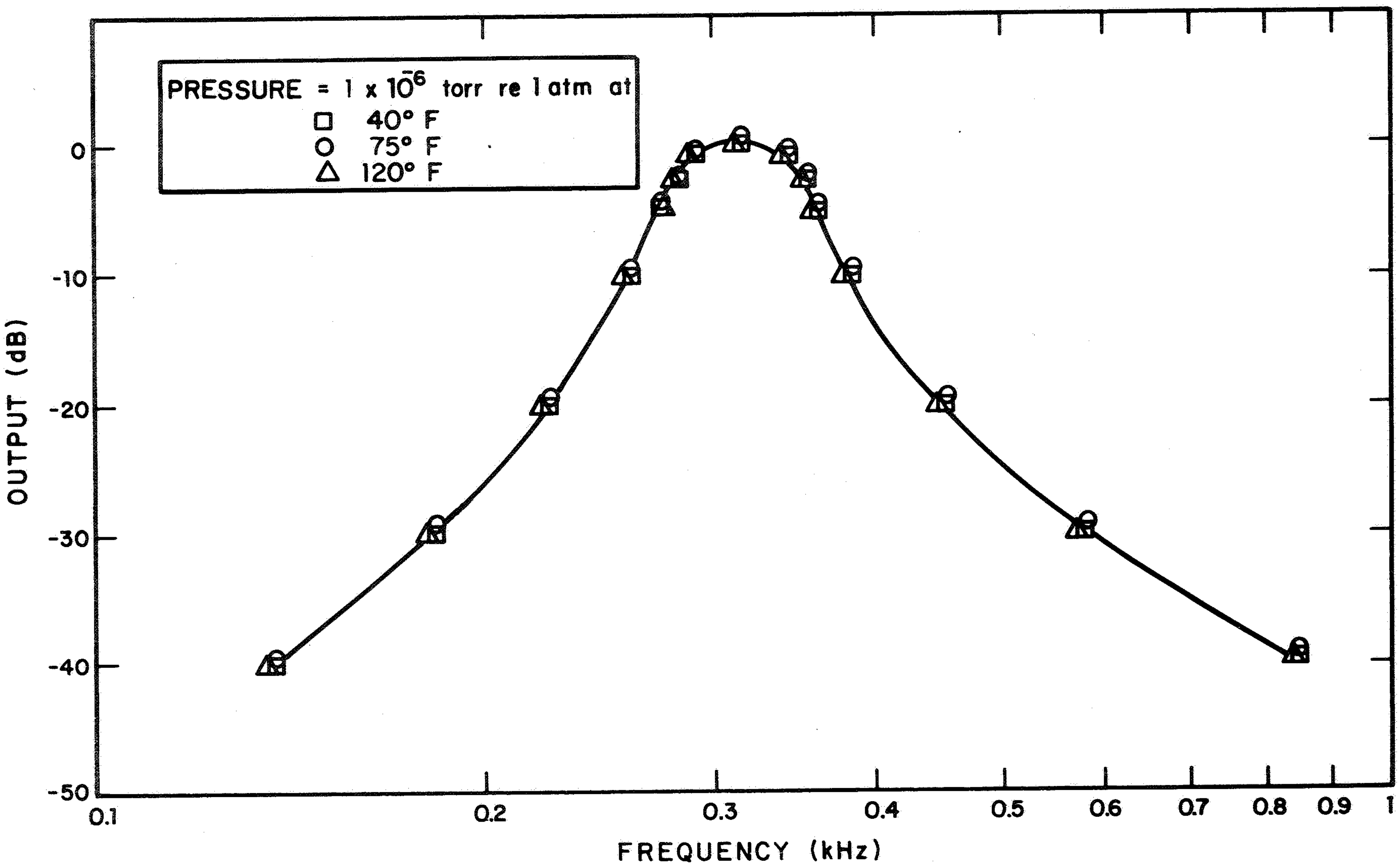


FIG. 12. FREQUENCY RESPONSE OF .316 kHz CHANNEL

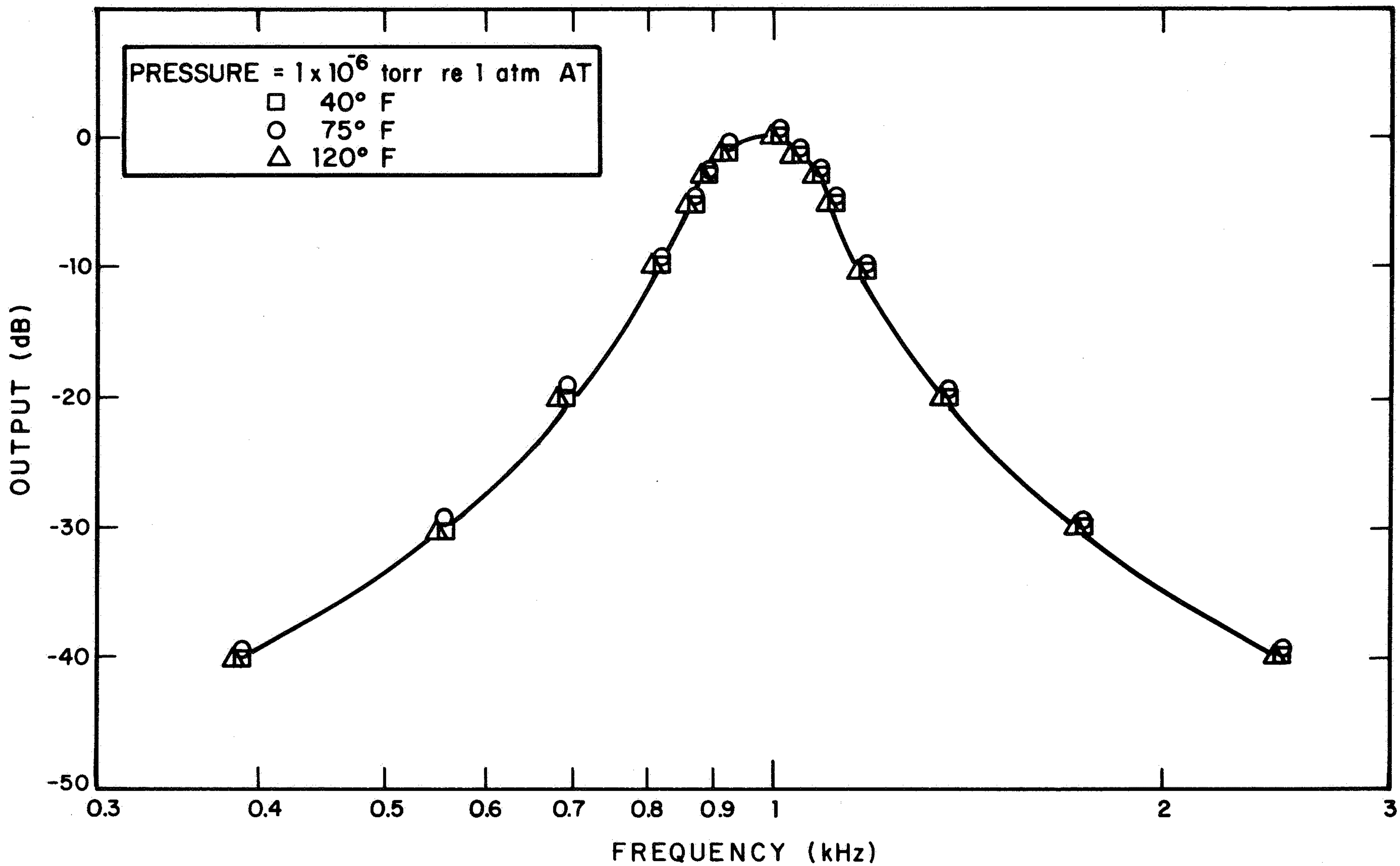


FIG. 13. FREQUENCY RESPONSE OF 1.0 kHz CHANNEL

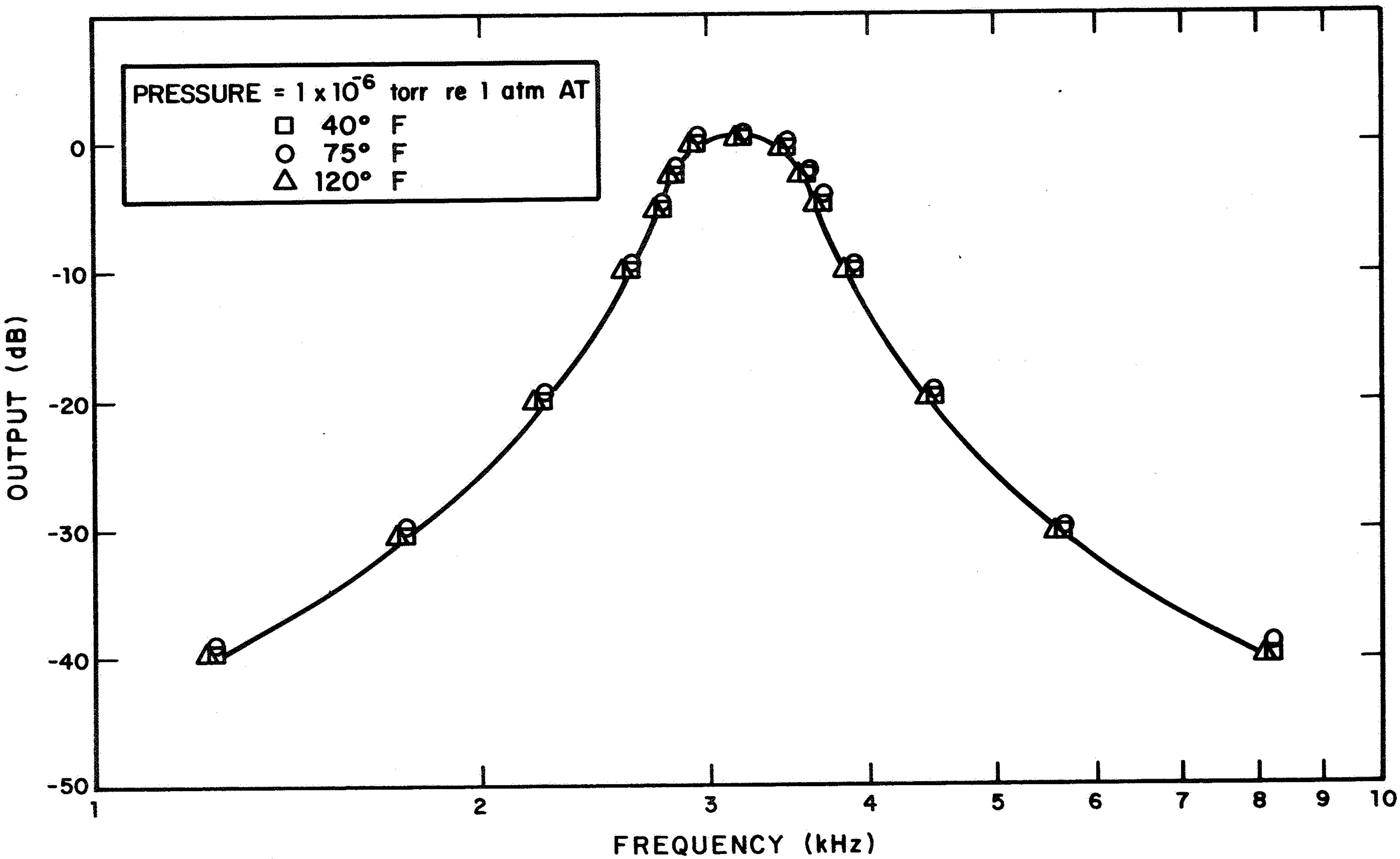


FIG. 14. FREQUENCY RESPONSE OF 3.16 kHz CHANNEL

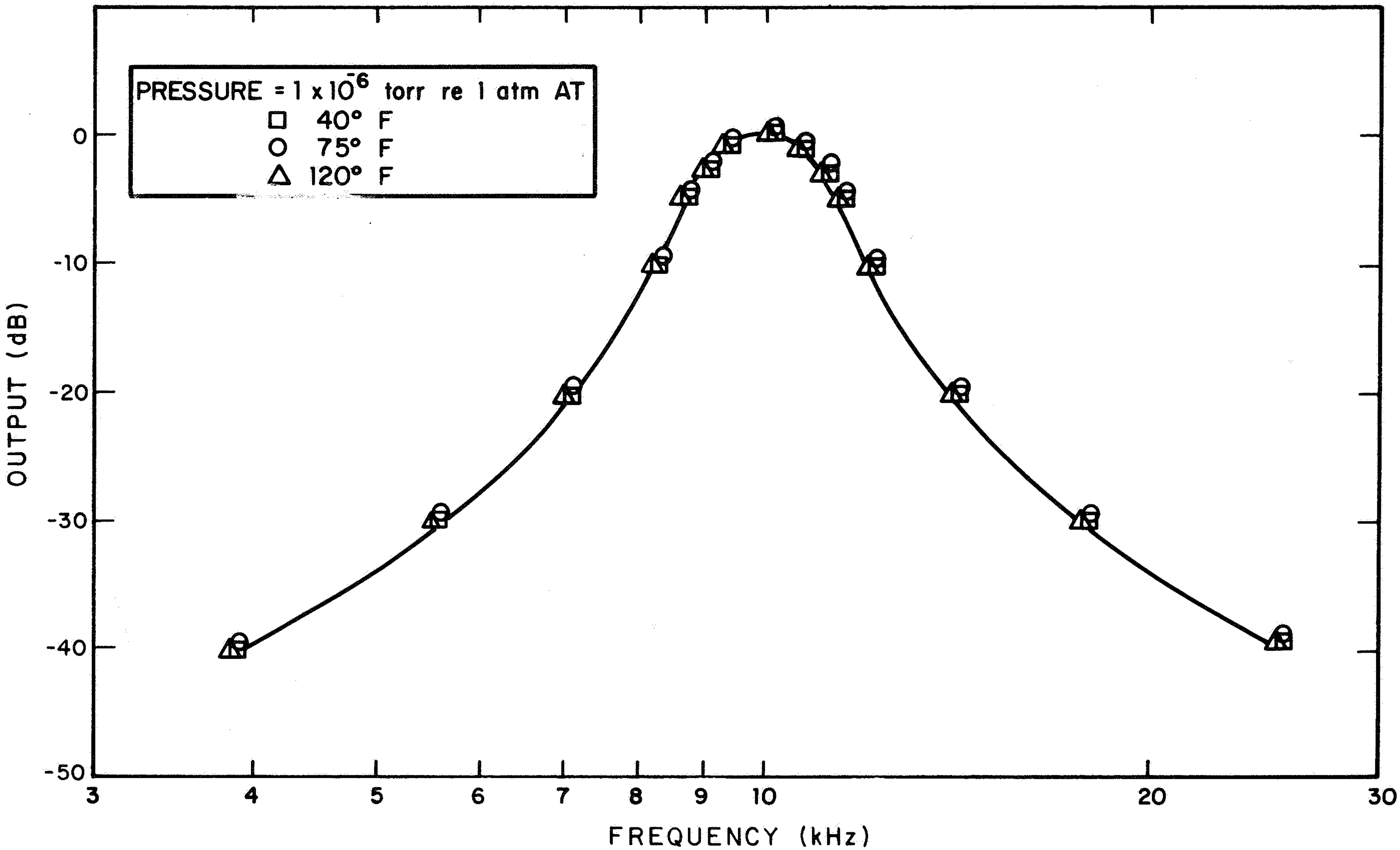


FIG. 15. FREQUENCY RESPONSE OF 10 kHz CHANNEL

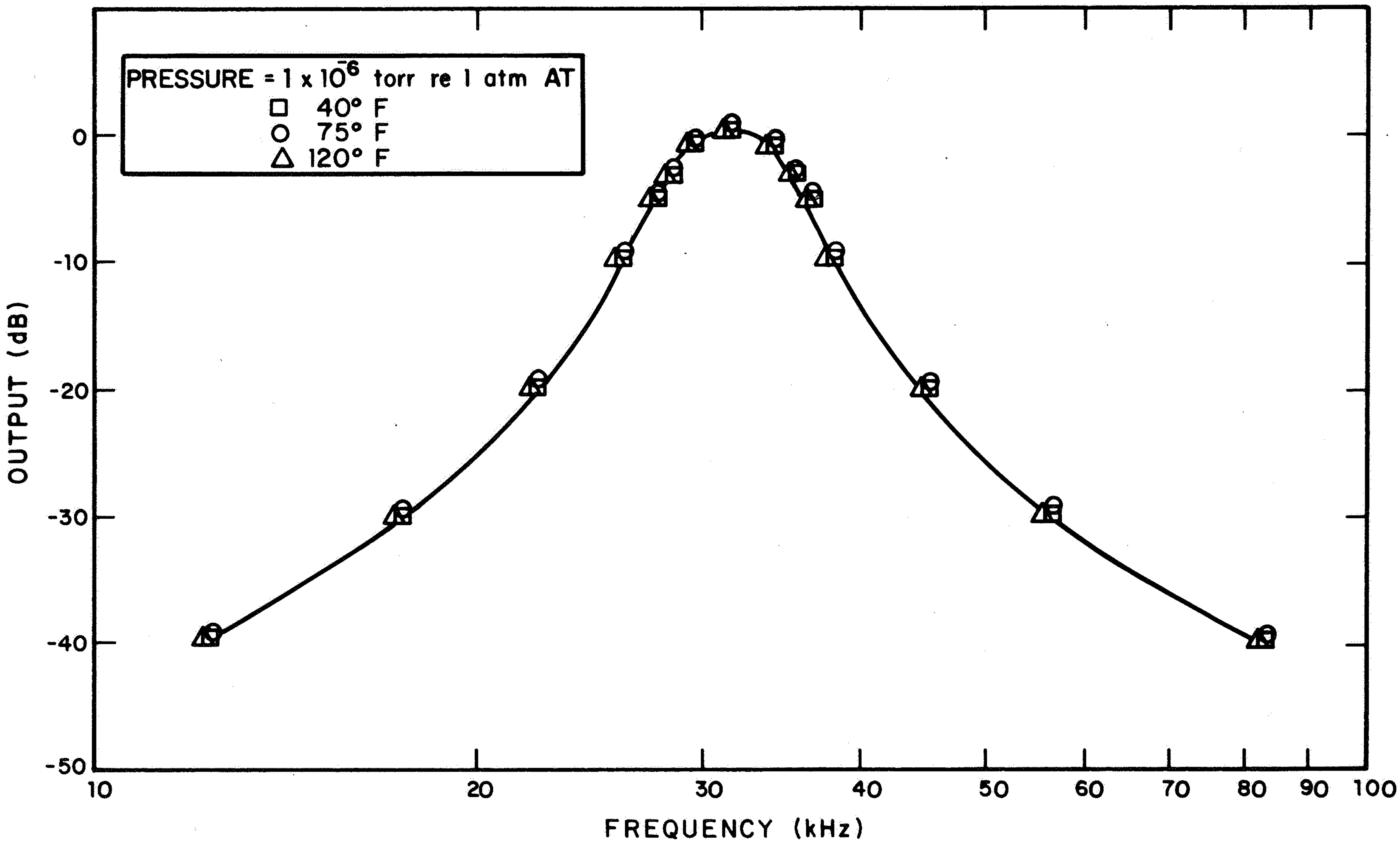


FIG. 16. FREQUENCY RESPONSE OF 31.6 kHz CHANNEL

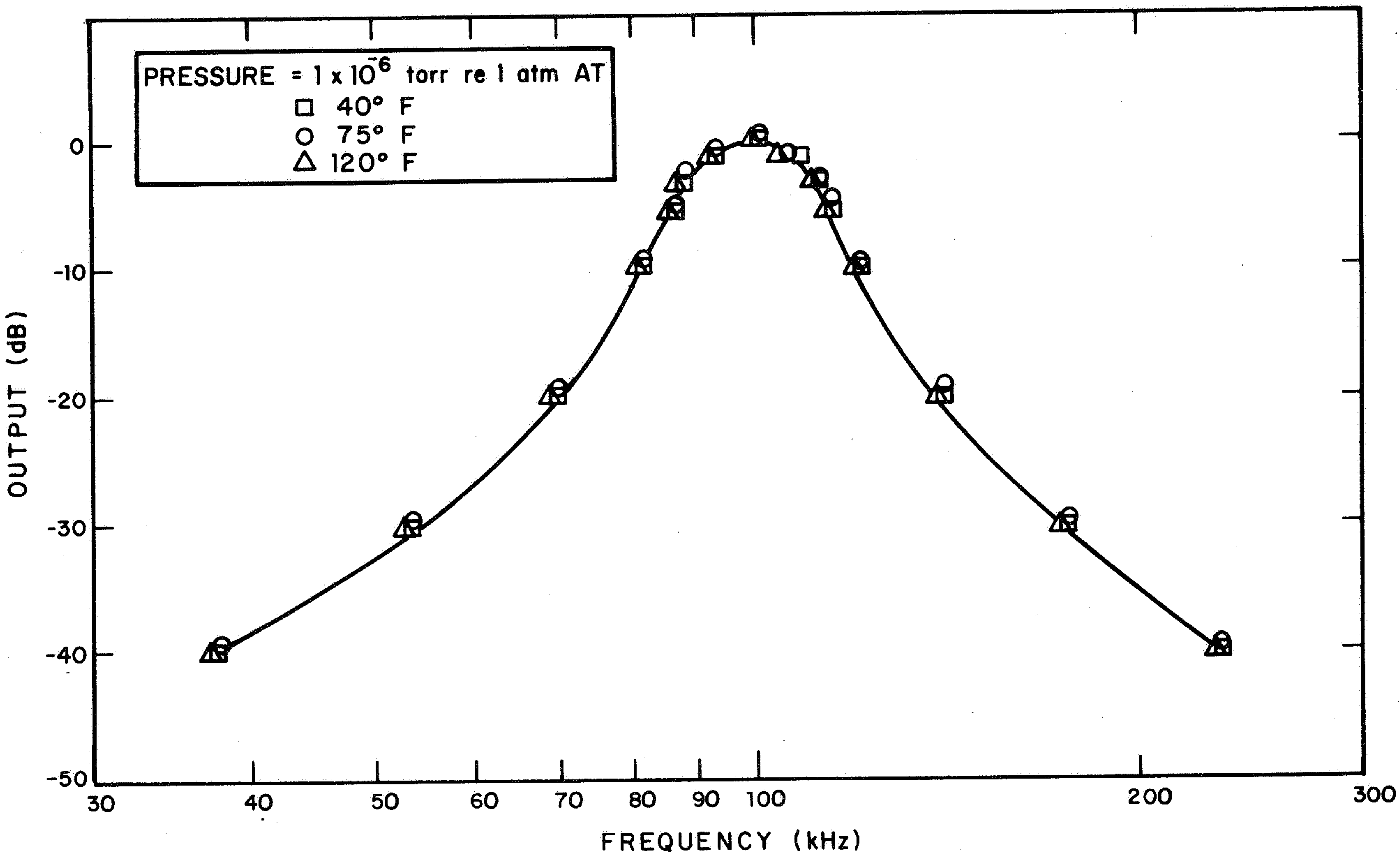


FIG. 17. FREQUENCY RESPONSE OF 100 kHz CHANNEL

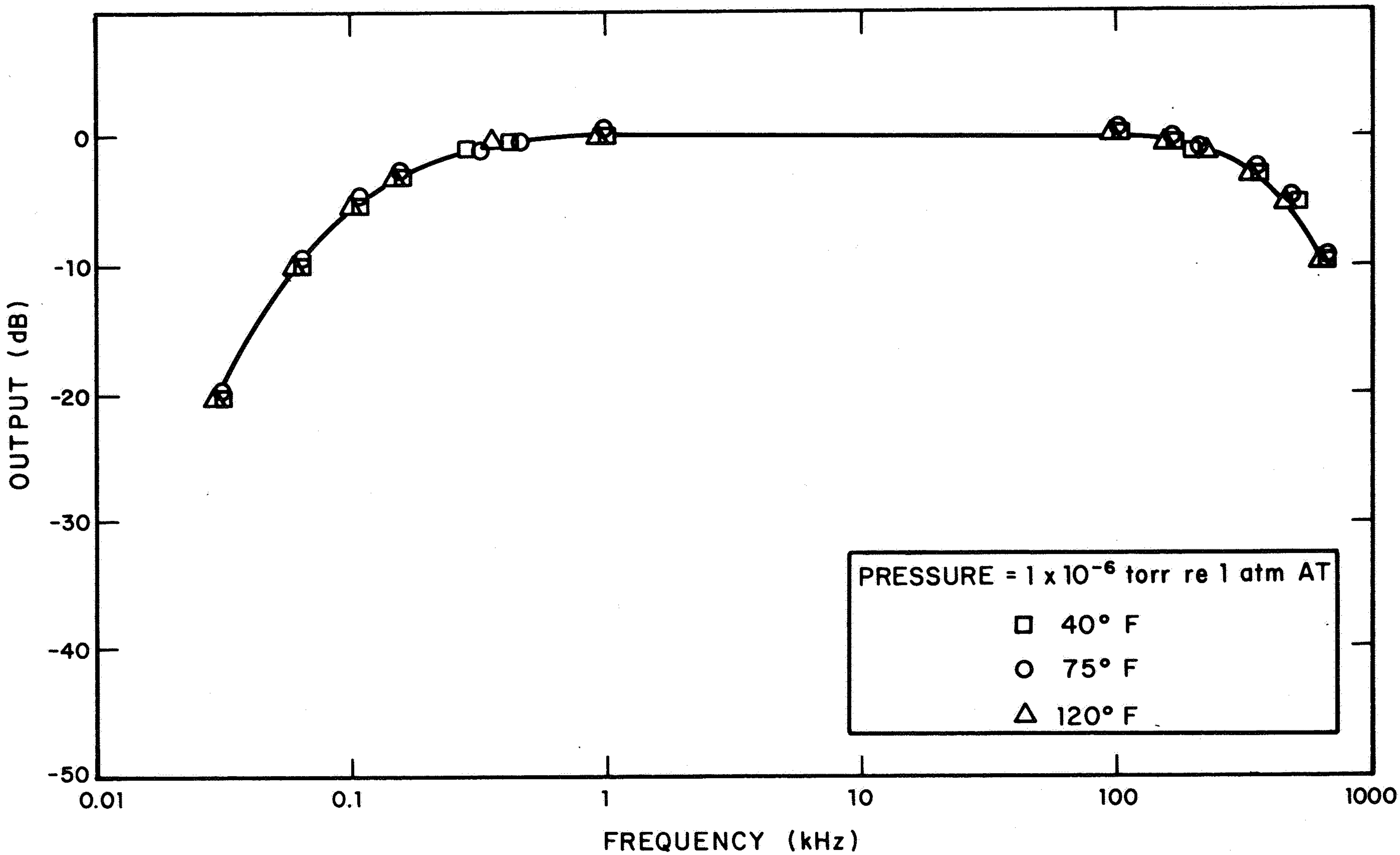


FIG. 18. FREQUENCY RESPONSE OF BROADBAND DETECTOR

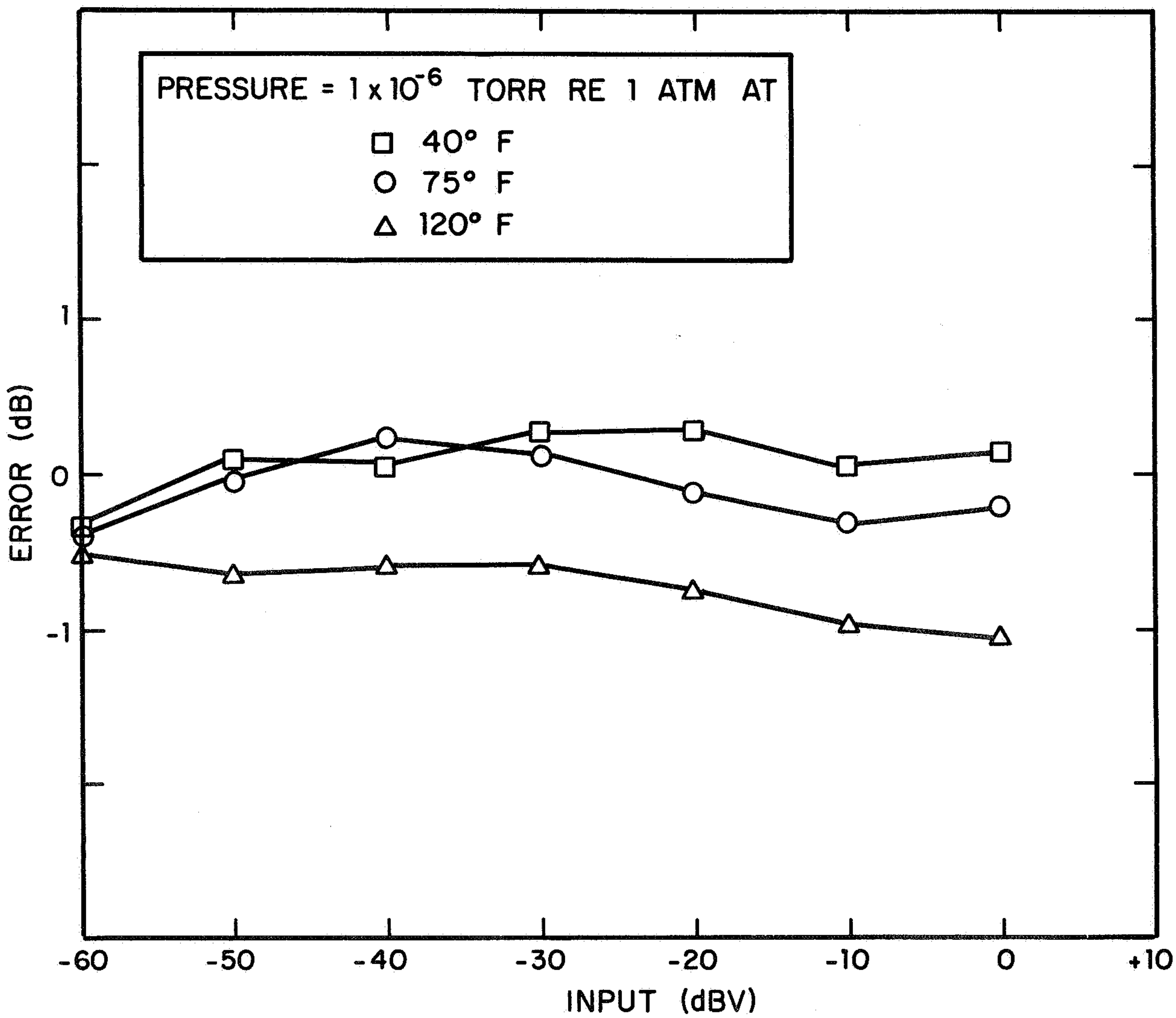


FIG. 19. LINEARITY ERROR OVER DYNAMIC RANGE OF .316 kHz CHANNEL

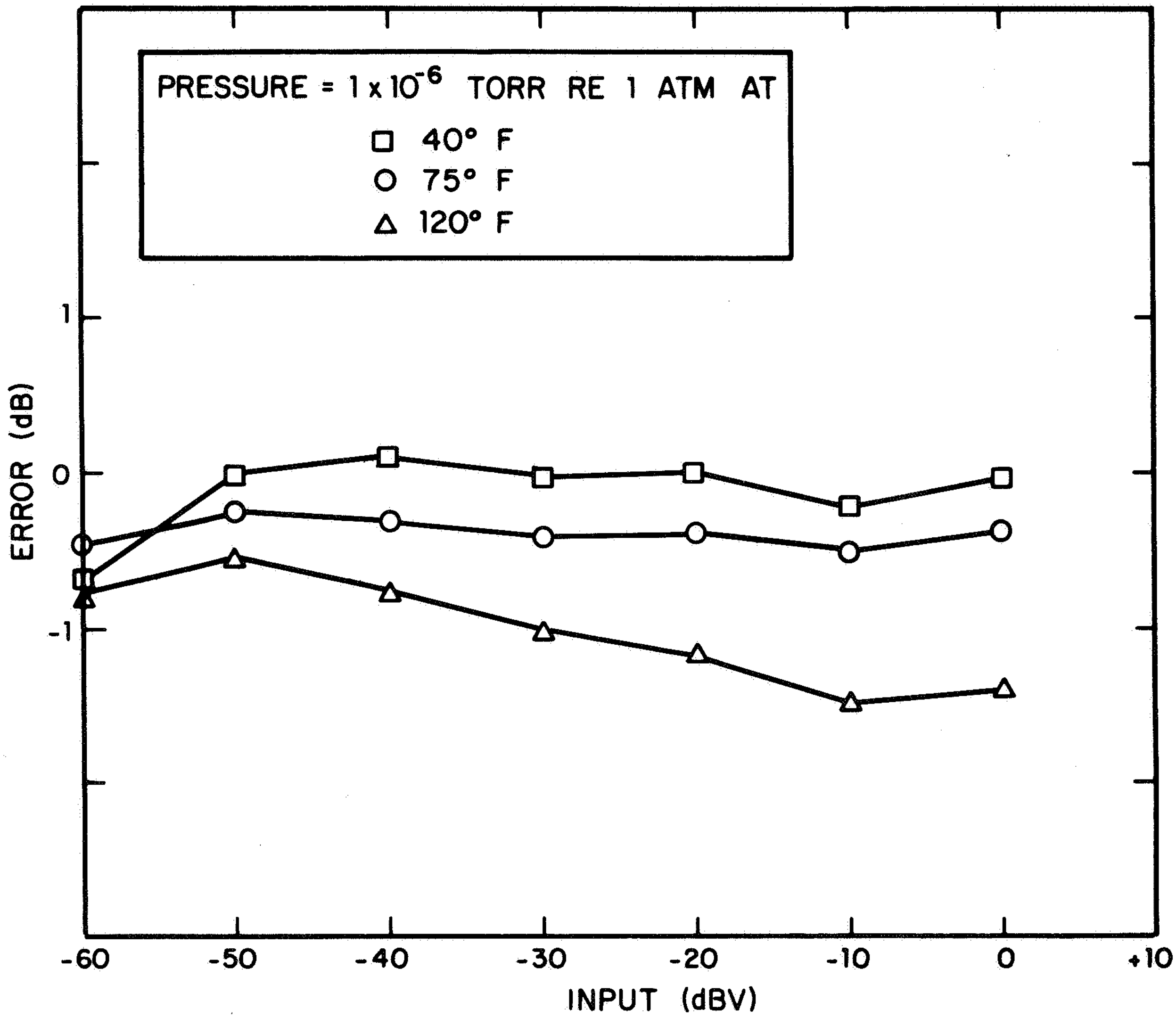


FIG. 20. LINEARITY ERROR OVER DYNAMIC RANGE OF 1 kHz CHANNEL

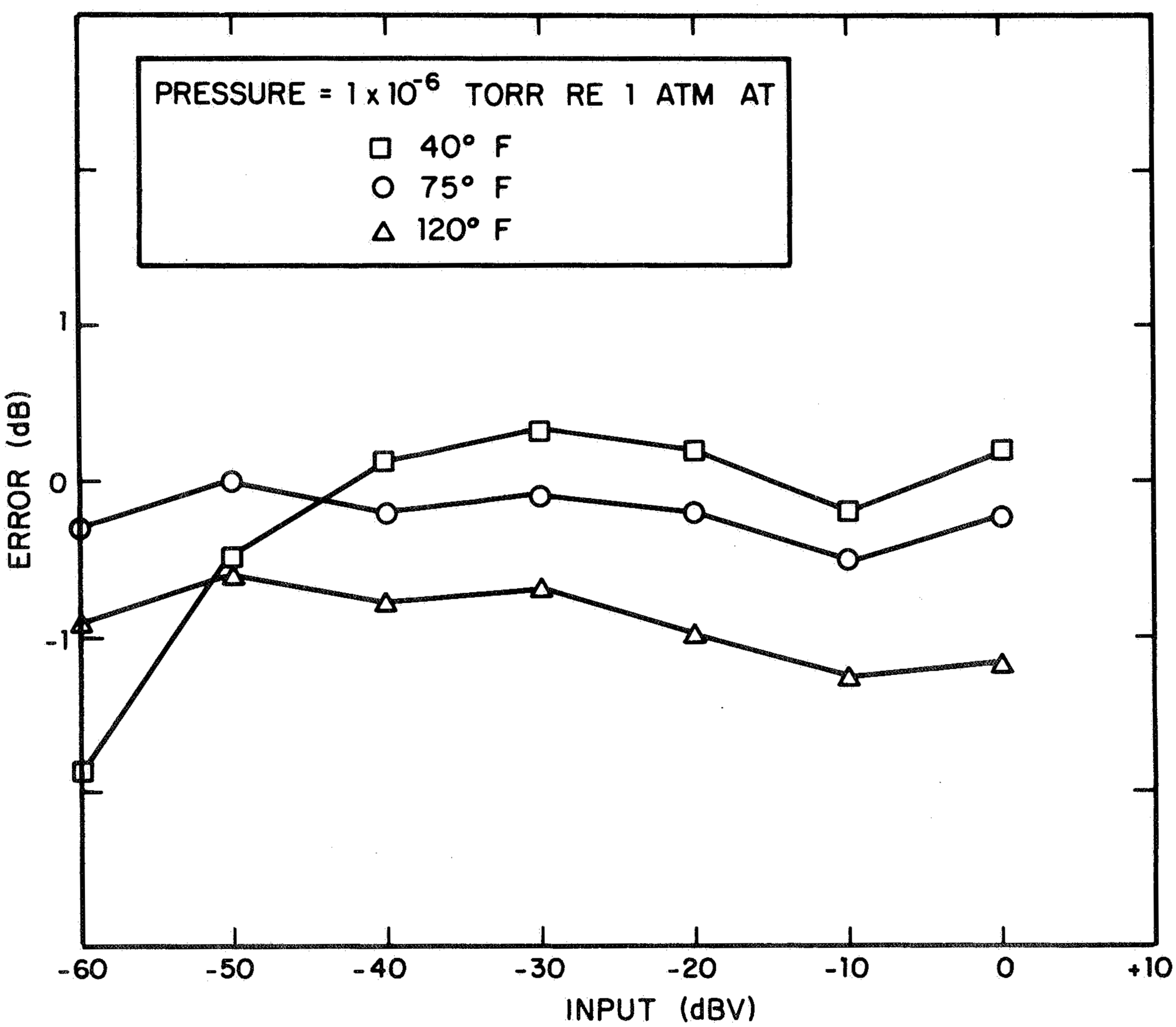


FIG. 21. LINEARITY ERROR OVER DYNAMIC RANGE OF 3.16 kHz CHANNEL

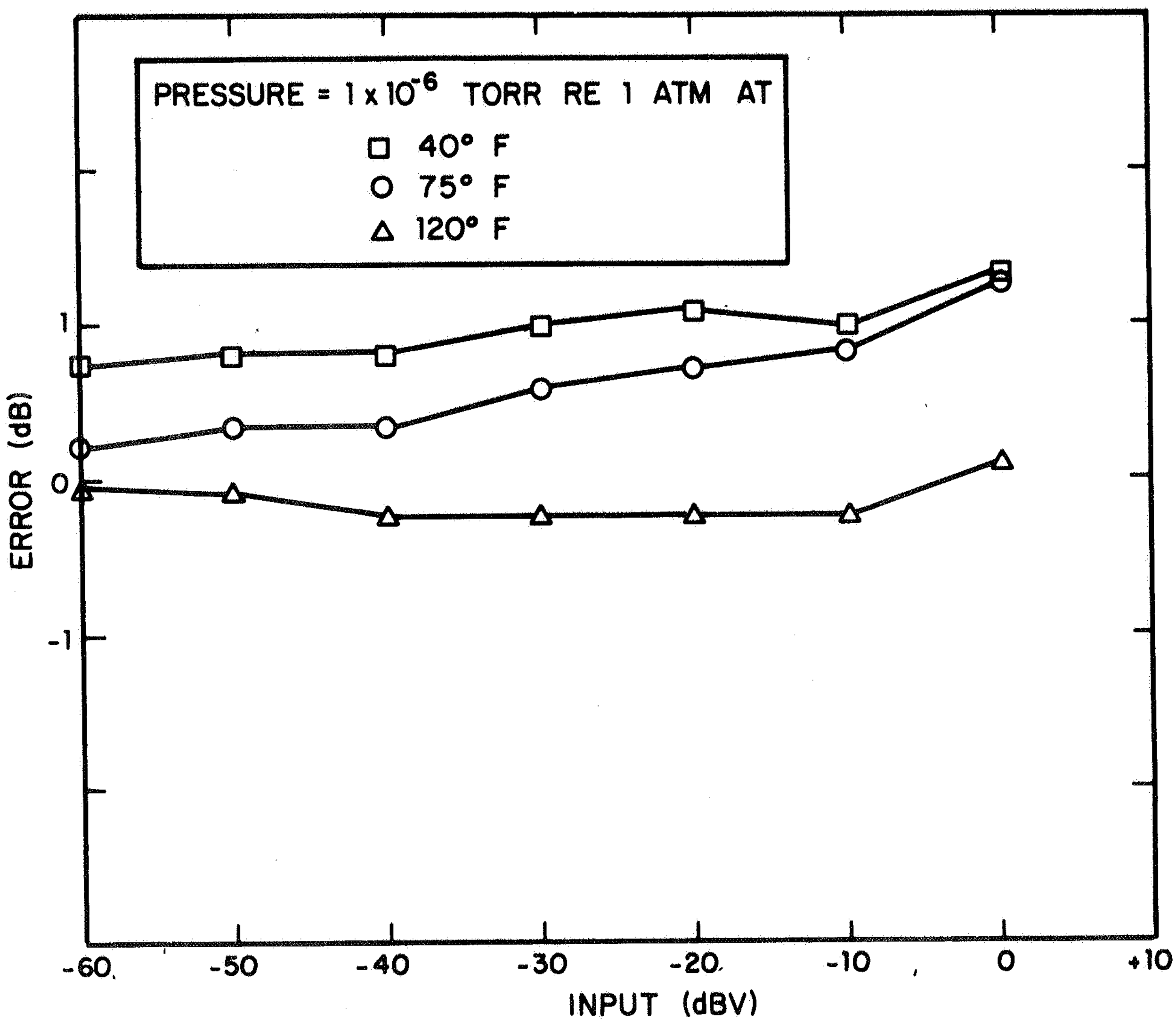


FIG. 22. LINEARITY ERROR OVER DYNAMIC RANGE OF 10 kHz CHANNEL

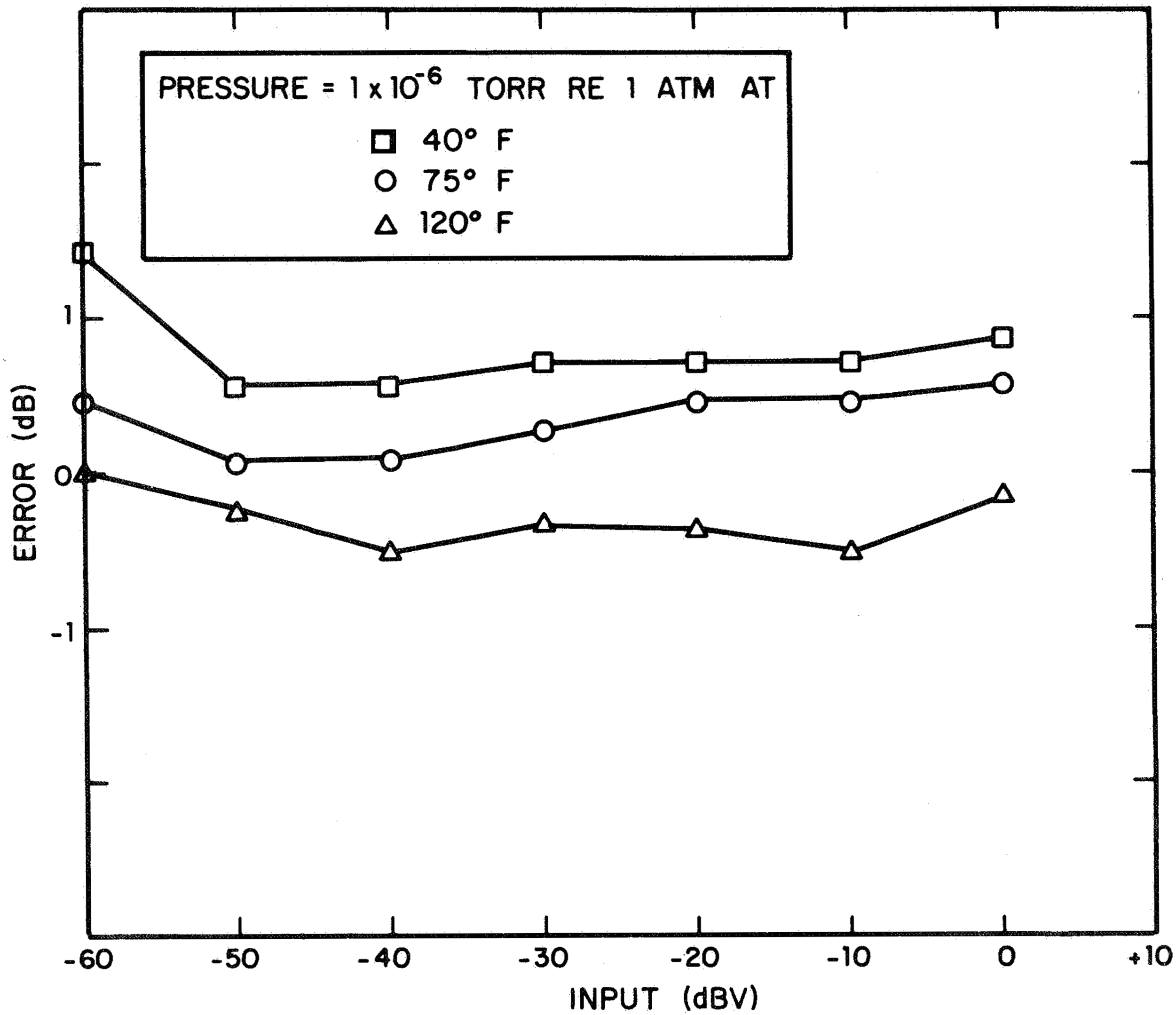


FIG. 23. LINEARITY ERROR OVER DYNAMIC RANGE OF 31.6 kHz CHANNEL

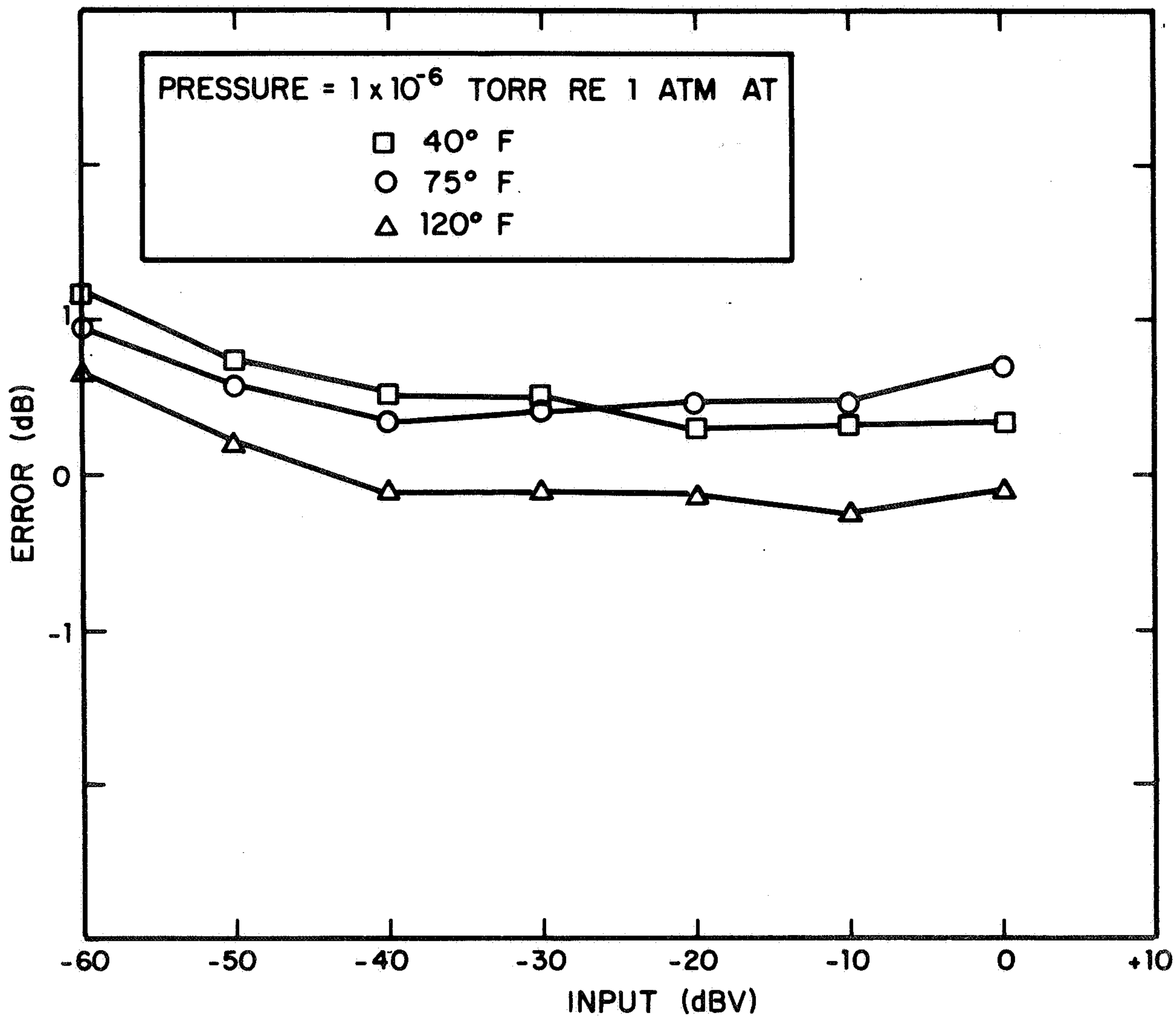


FIG. 24. LINEARITY ERROR OVER DYNAMIC RANGE OF 100 kHz CHANNEL

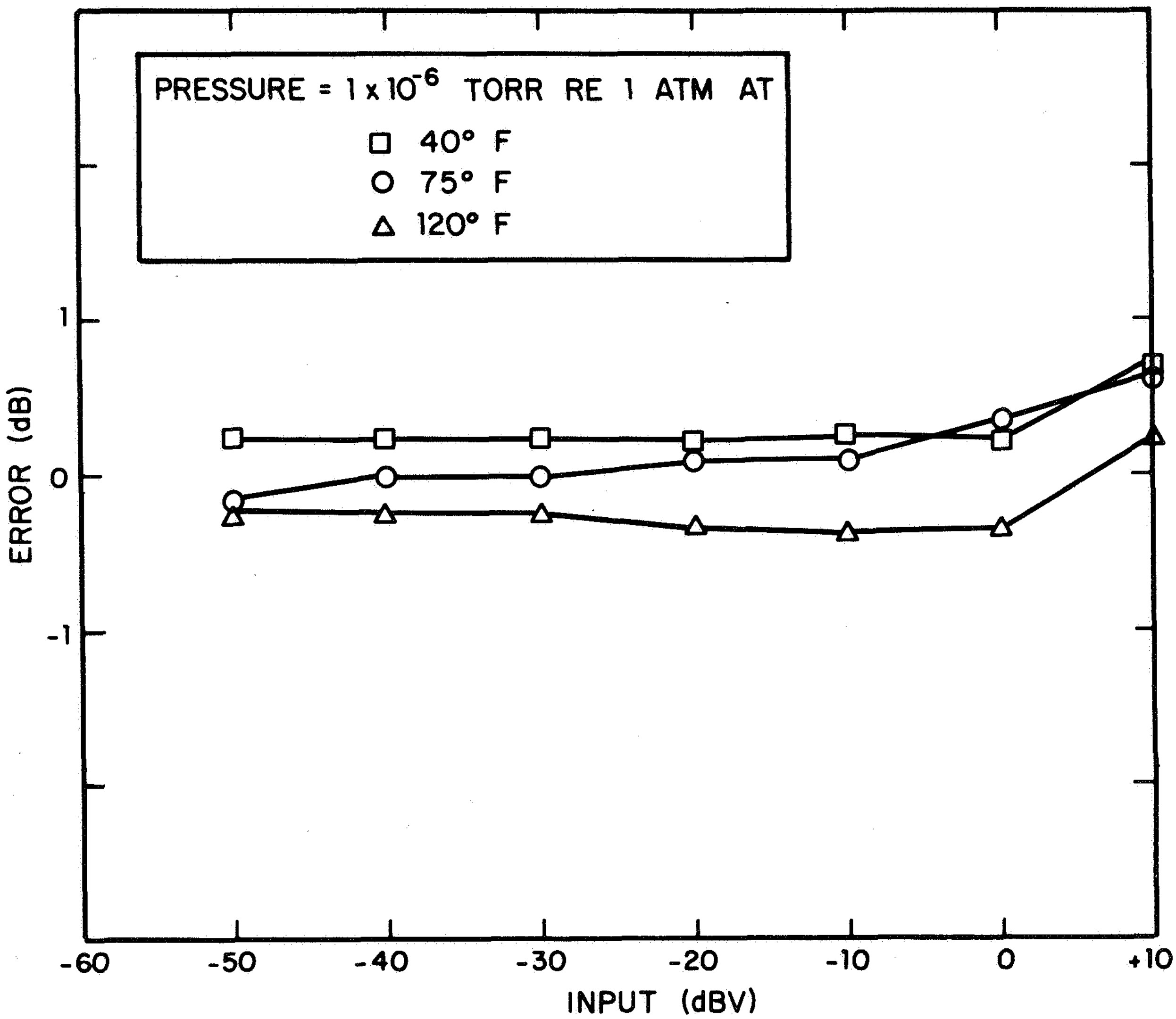


FIG. 25. LINEARITY ERROR OVER DYNAMIC RANGE OF BROADBAND DETECTOR AT 1 kHz

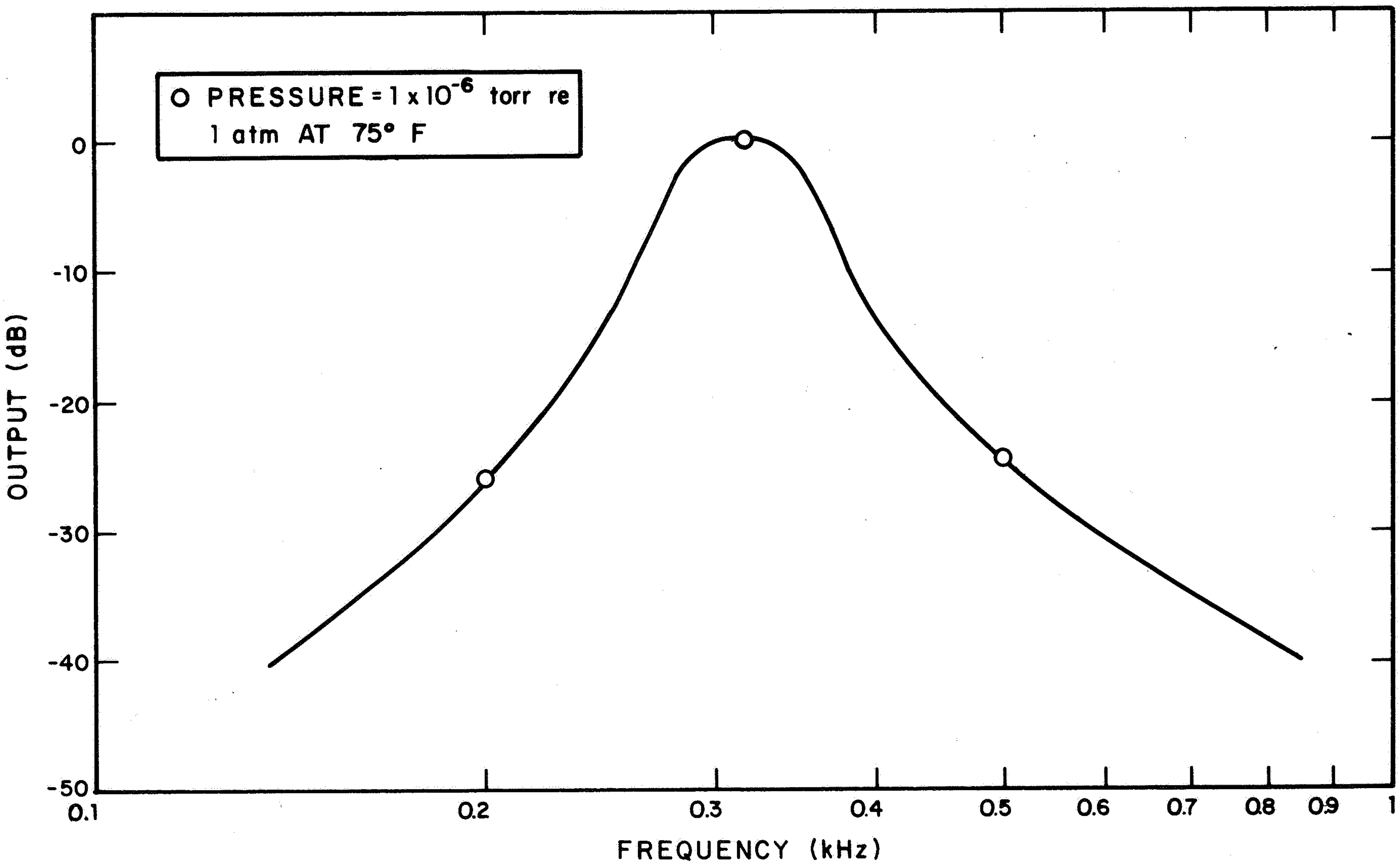


FIG. 26. SPOT VERIFICATION — FREQUENCY RESPONSE OF .316 kHz CHANNEL

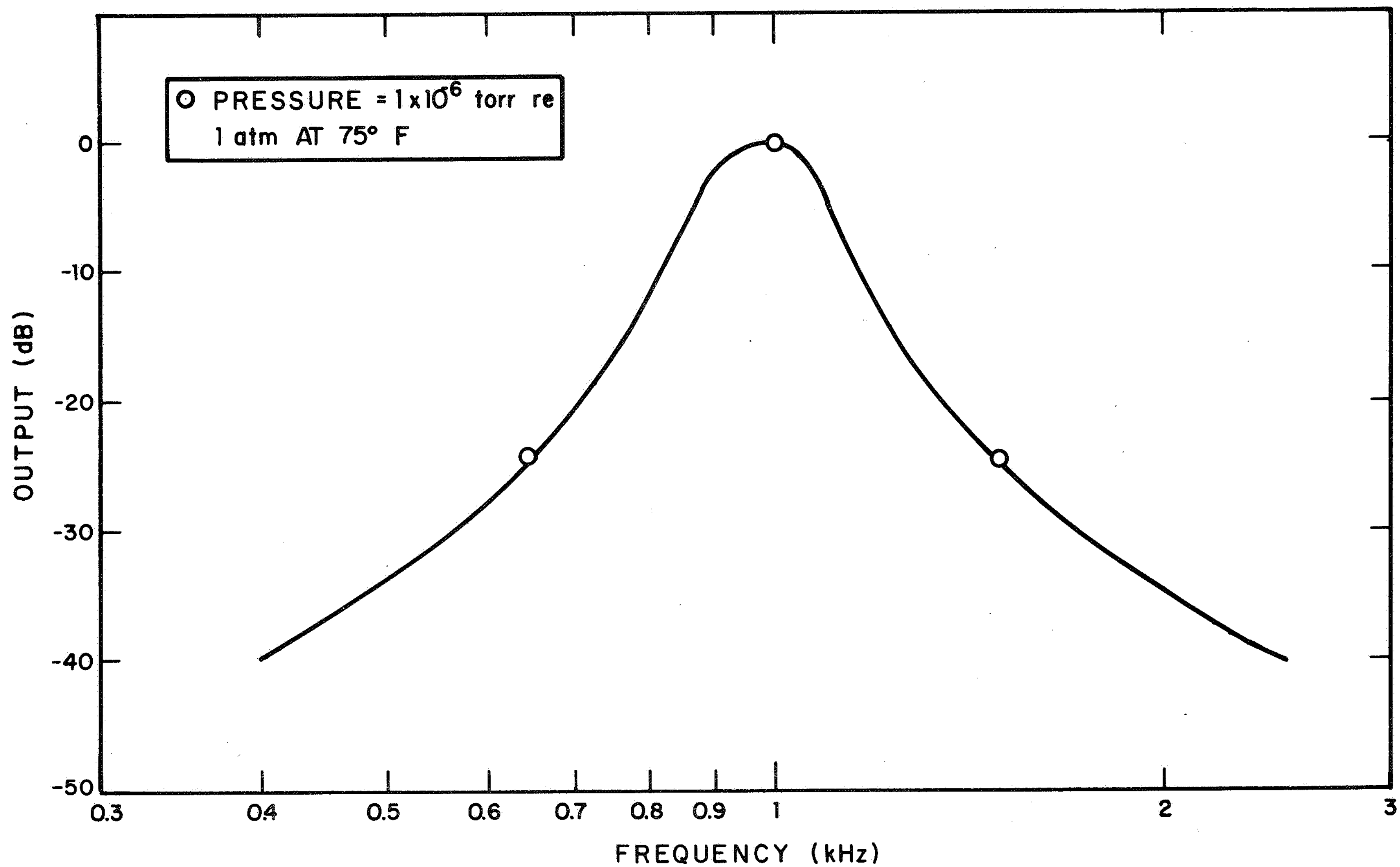


FIG. 27. SPOT VERIFICATION — FREQUENCY RESPONSE OF 1.0 kHz CHANNEL

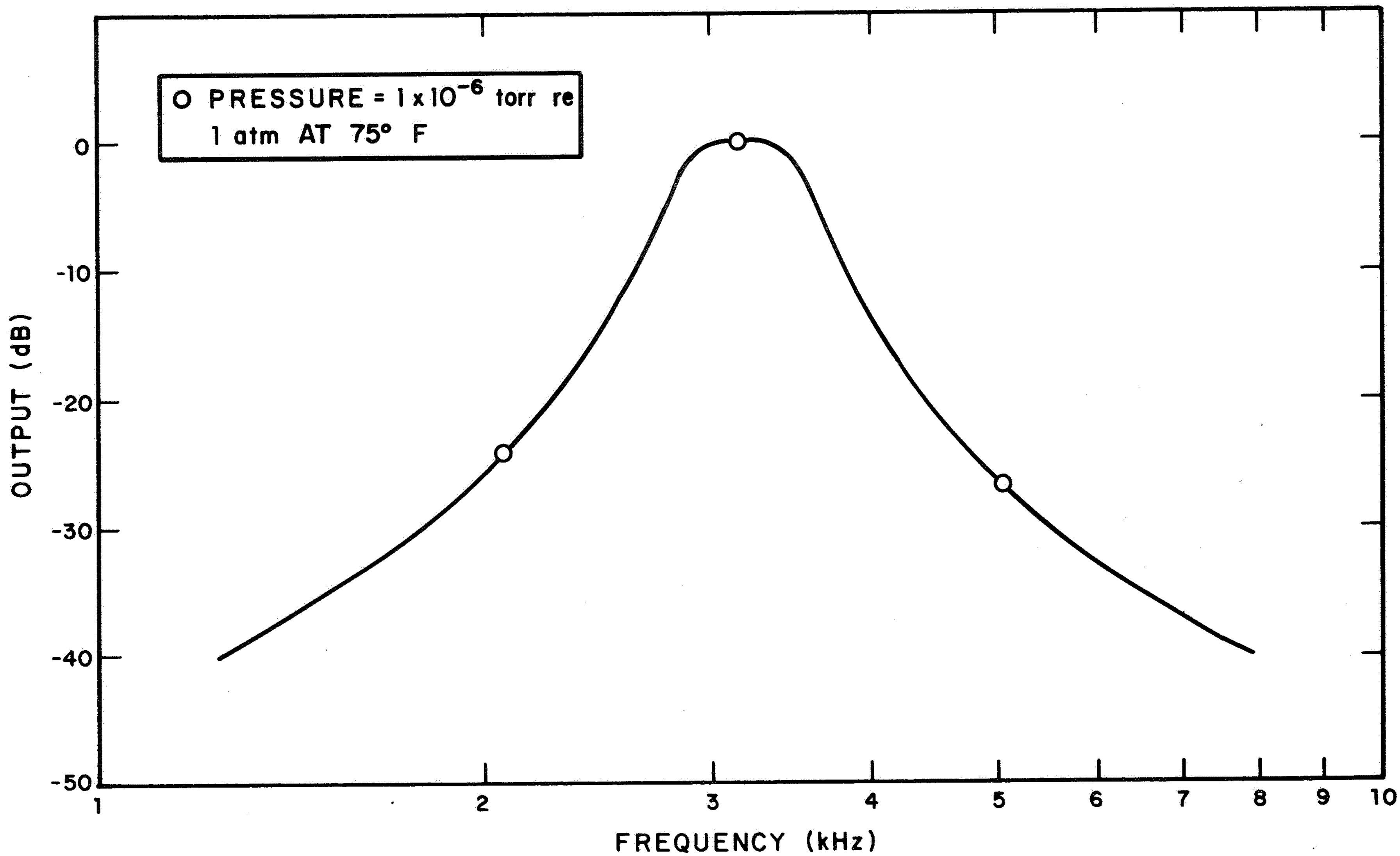


FIG. 28. SPOT VERIFICATION — FREQUENCY RESPONSE OF 3.16 kHz CHANNEL

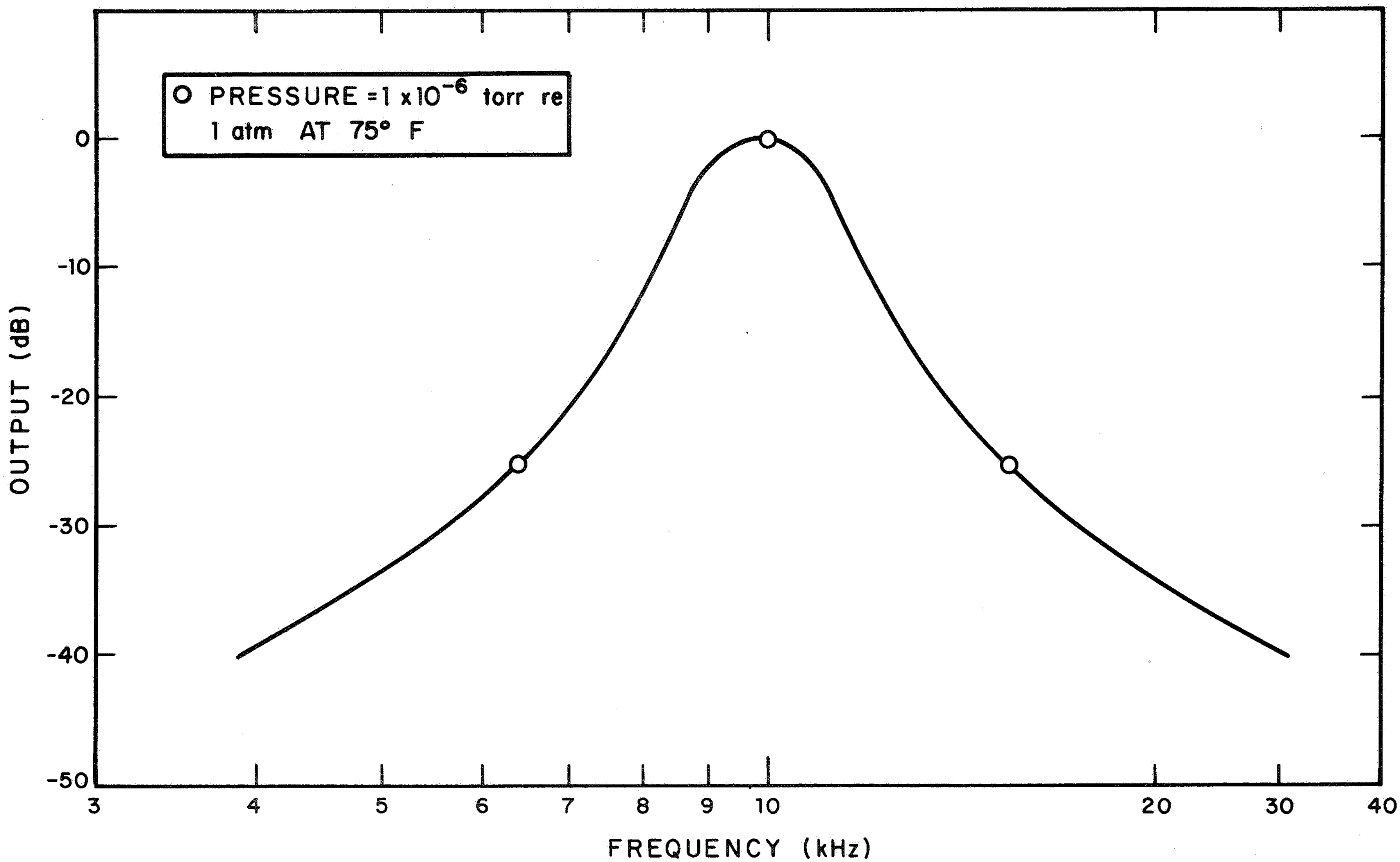


FIG. 29. SPOT VERIFICATION — FREQUENCY RESPONSE OF 10 kHz CHANNEL

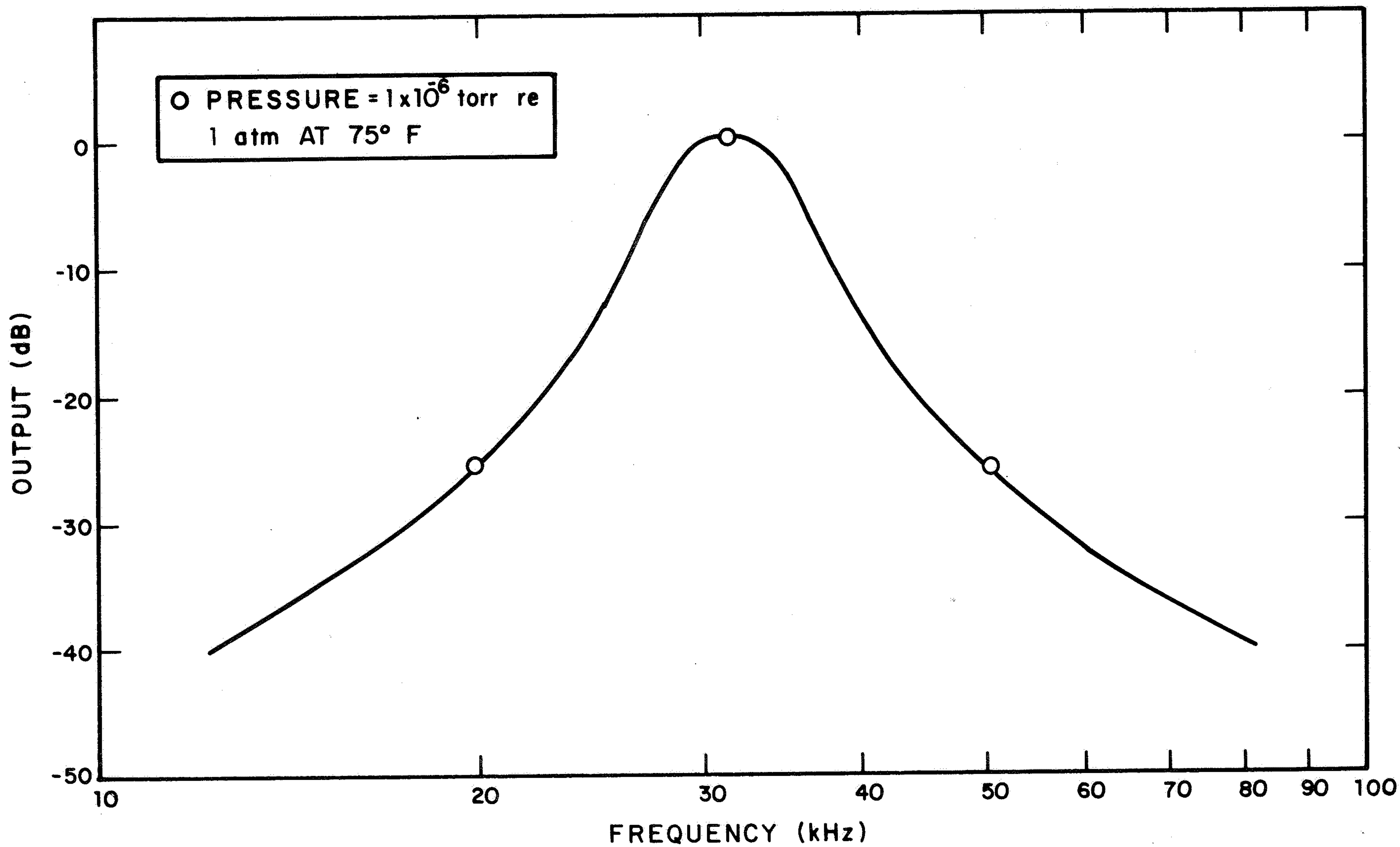


FIG. 30. SPOT VERIFICATION — FREQUENCY RESPONSE OF 31.6 kHz CHANNEL

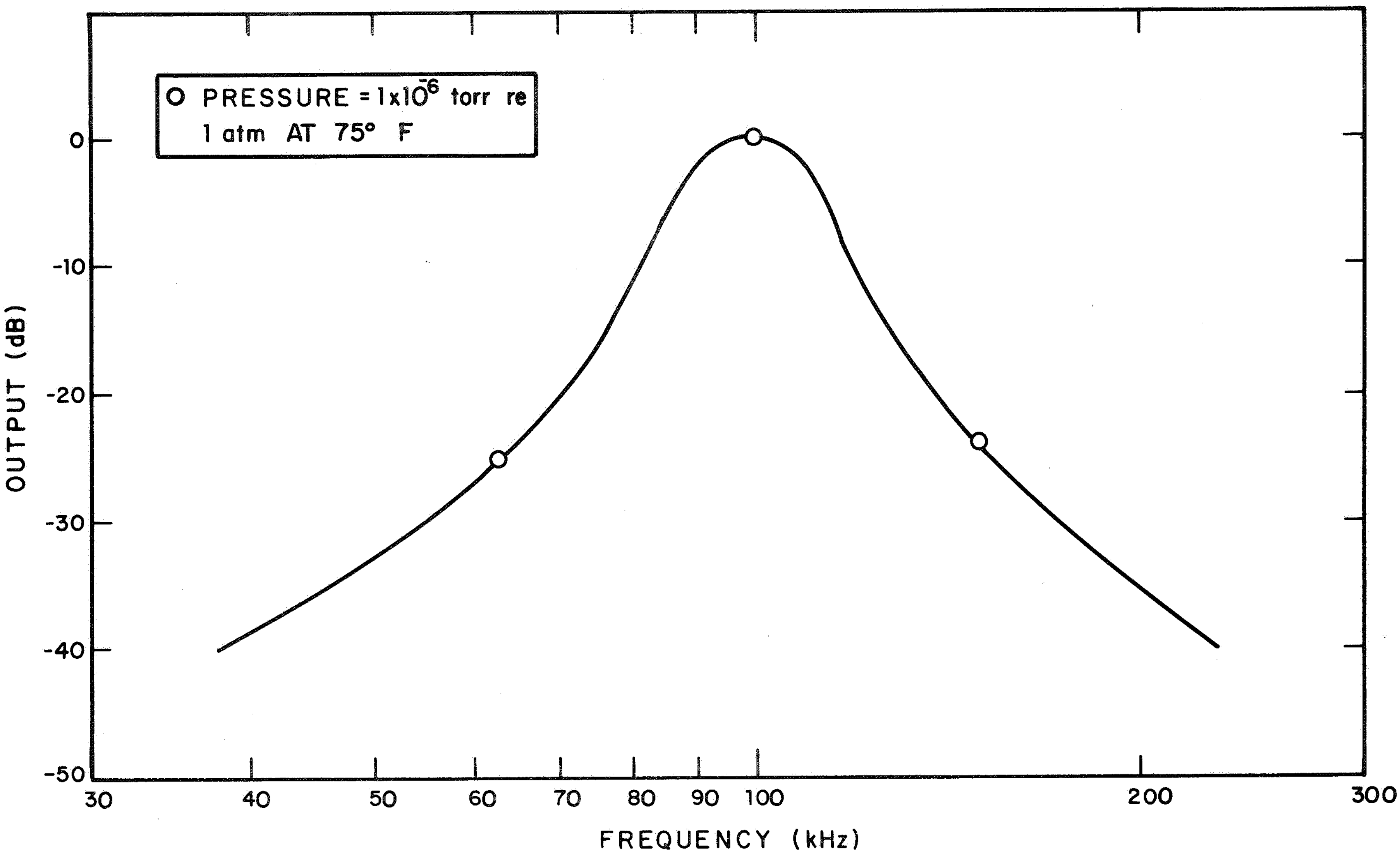


FIG. 31. SPOT VERIFICATION — FREQUENCY RESPONSE OF 100 kHz CHANNEL

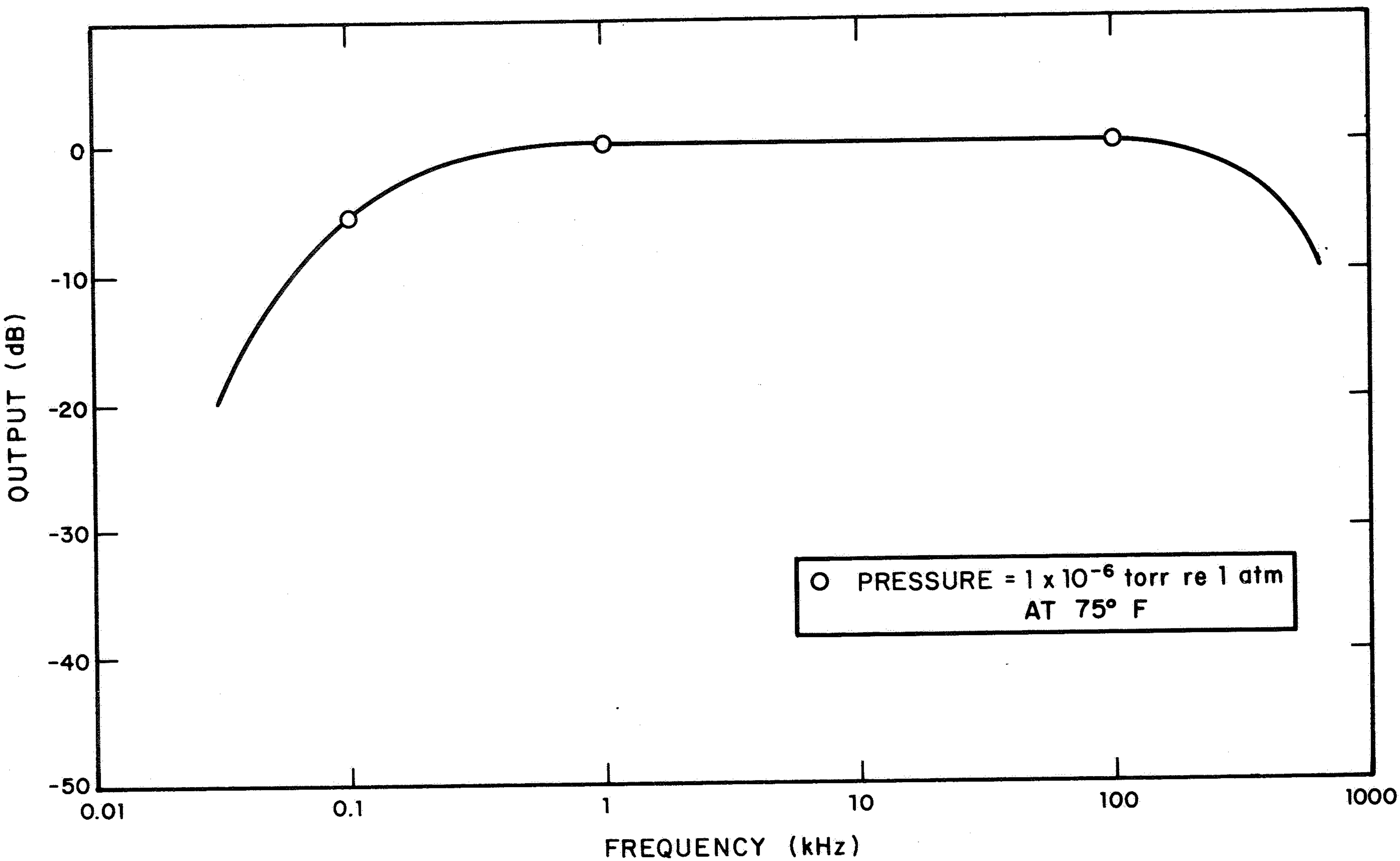


FIG. 32. SPOT VERIFICATION — FREQUENCY RESPONSE OF BROADBAND DETECTOR CHANNEL

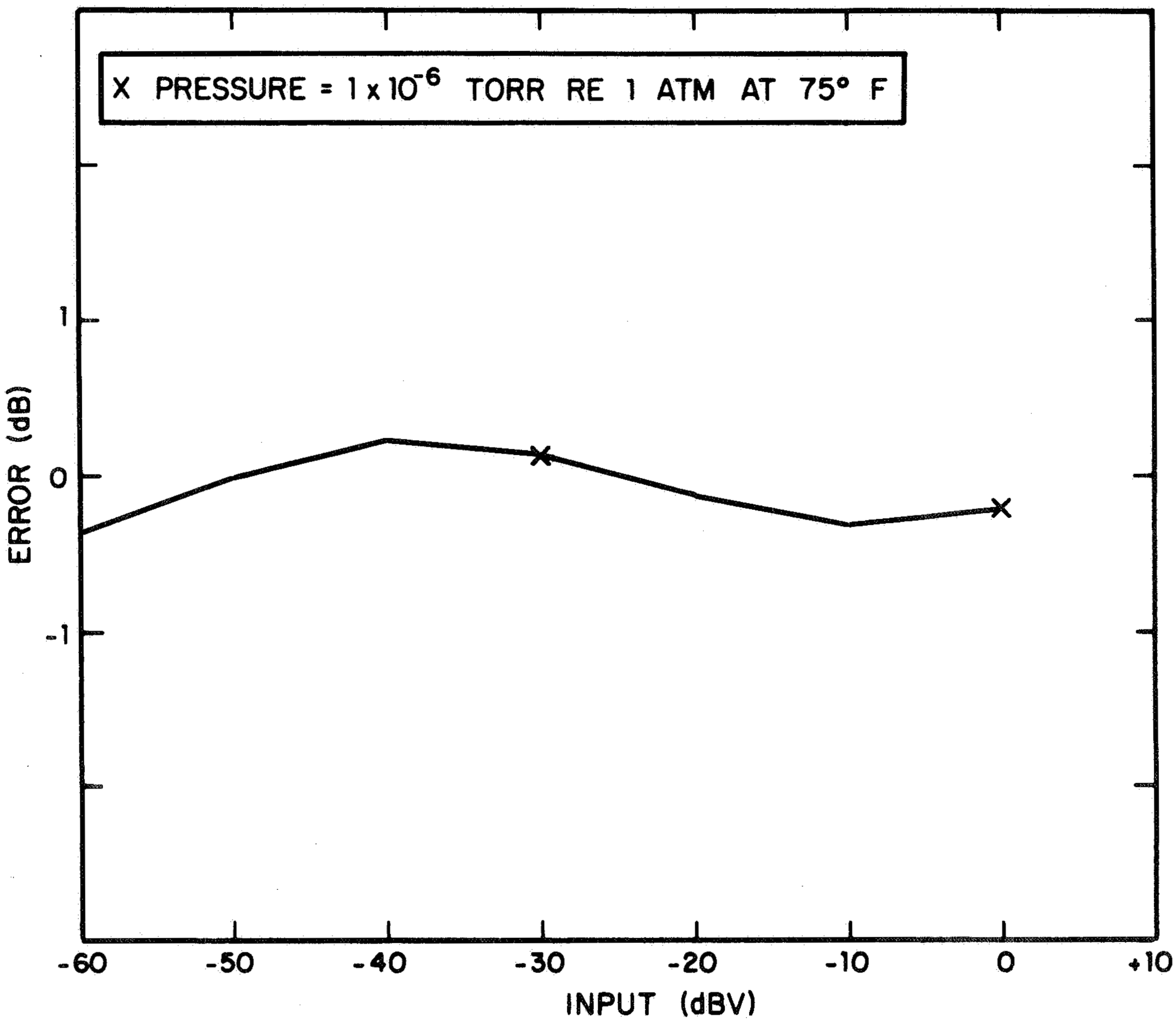


FIG. 33. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF .316 kHz CHANNEL

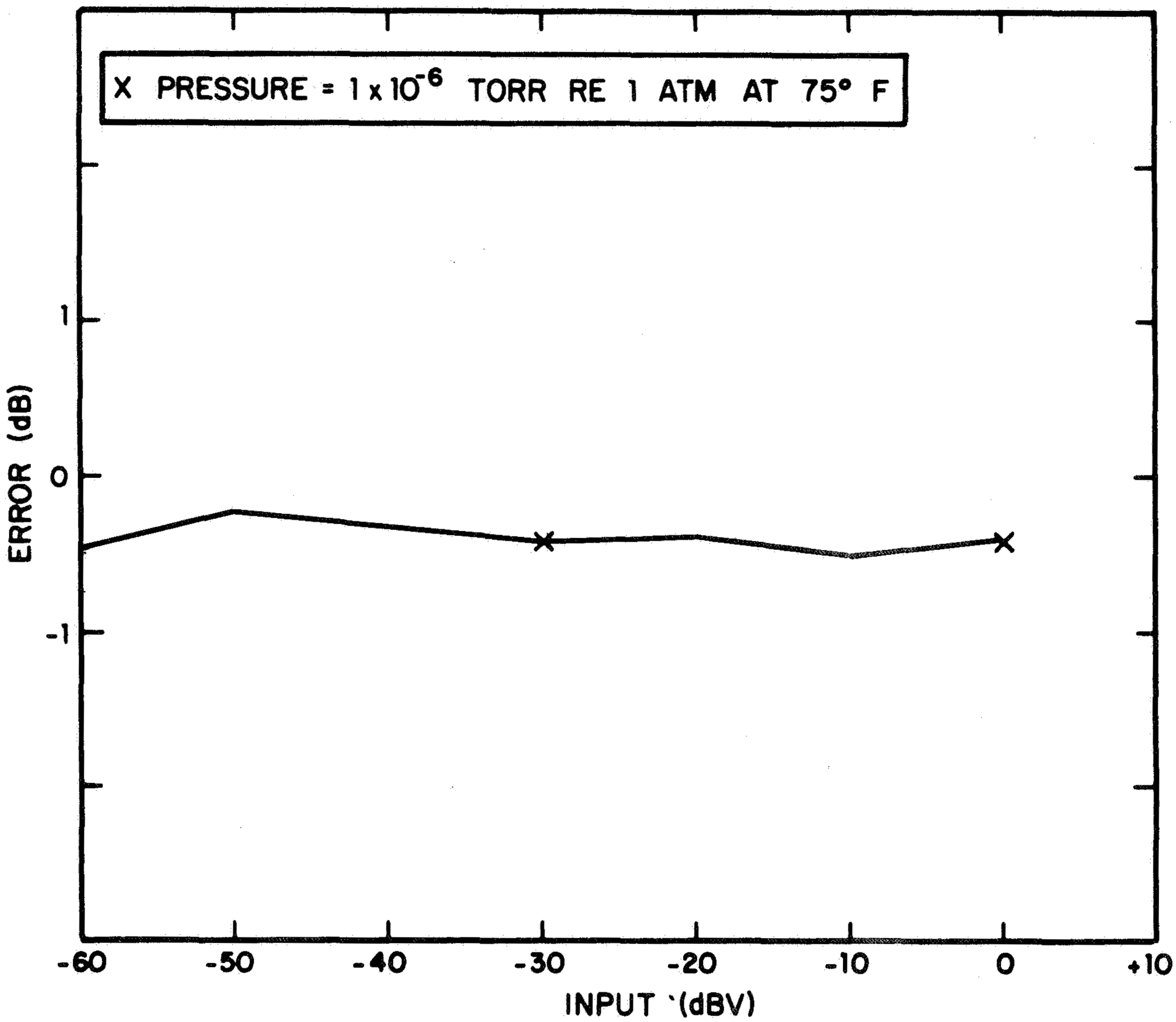


FIG. 34. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF 1 kHz CHANNEL

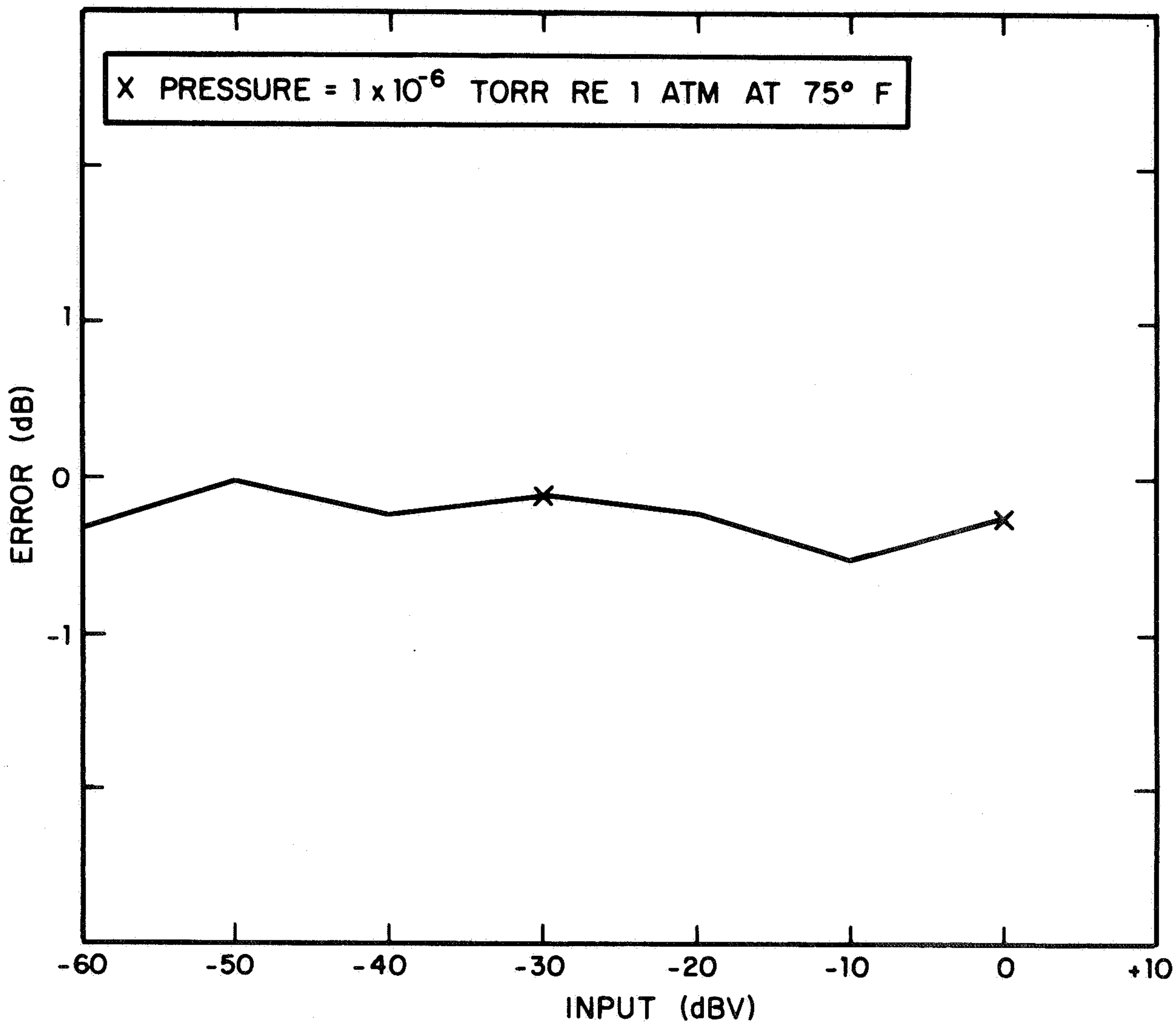


FIG. 35. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF 3.16 kHz CHANNEL

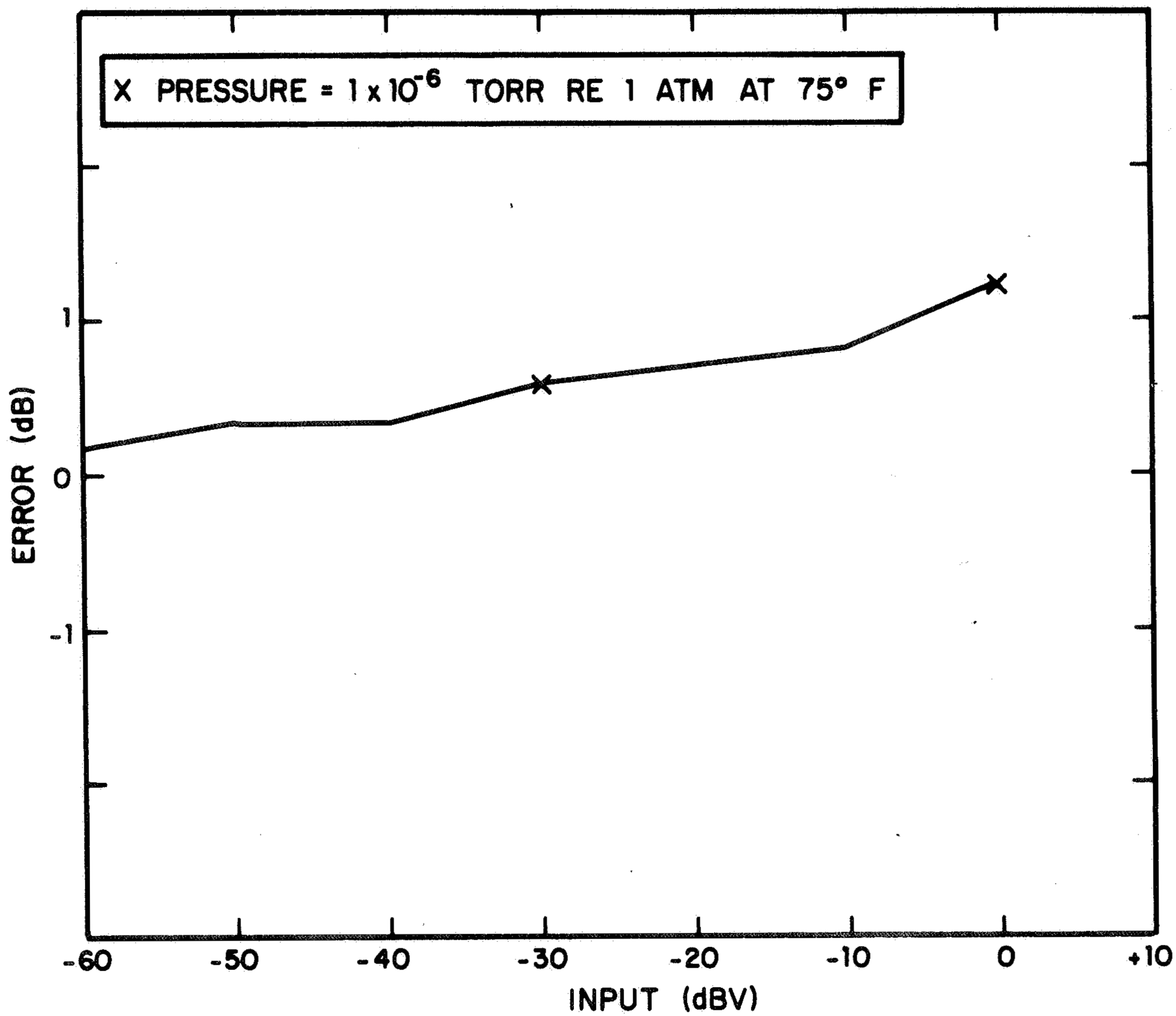


FIG. 36. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF 10 kHz CHANNEL

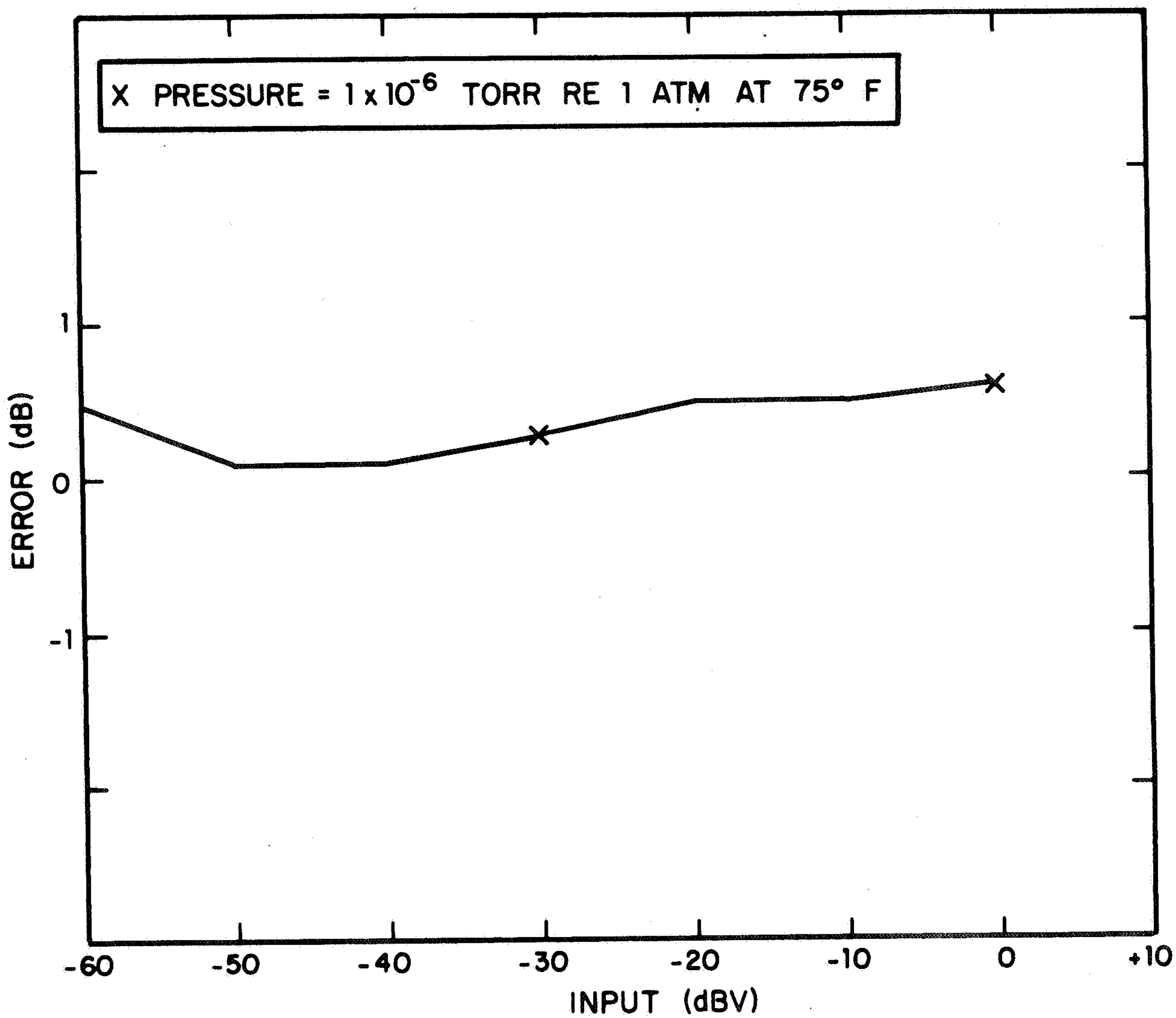


FIG. 37. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF 31.6 kHz CHANNEL

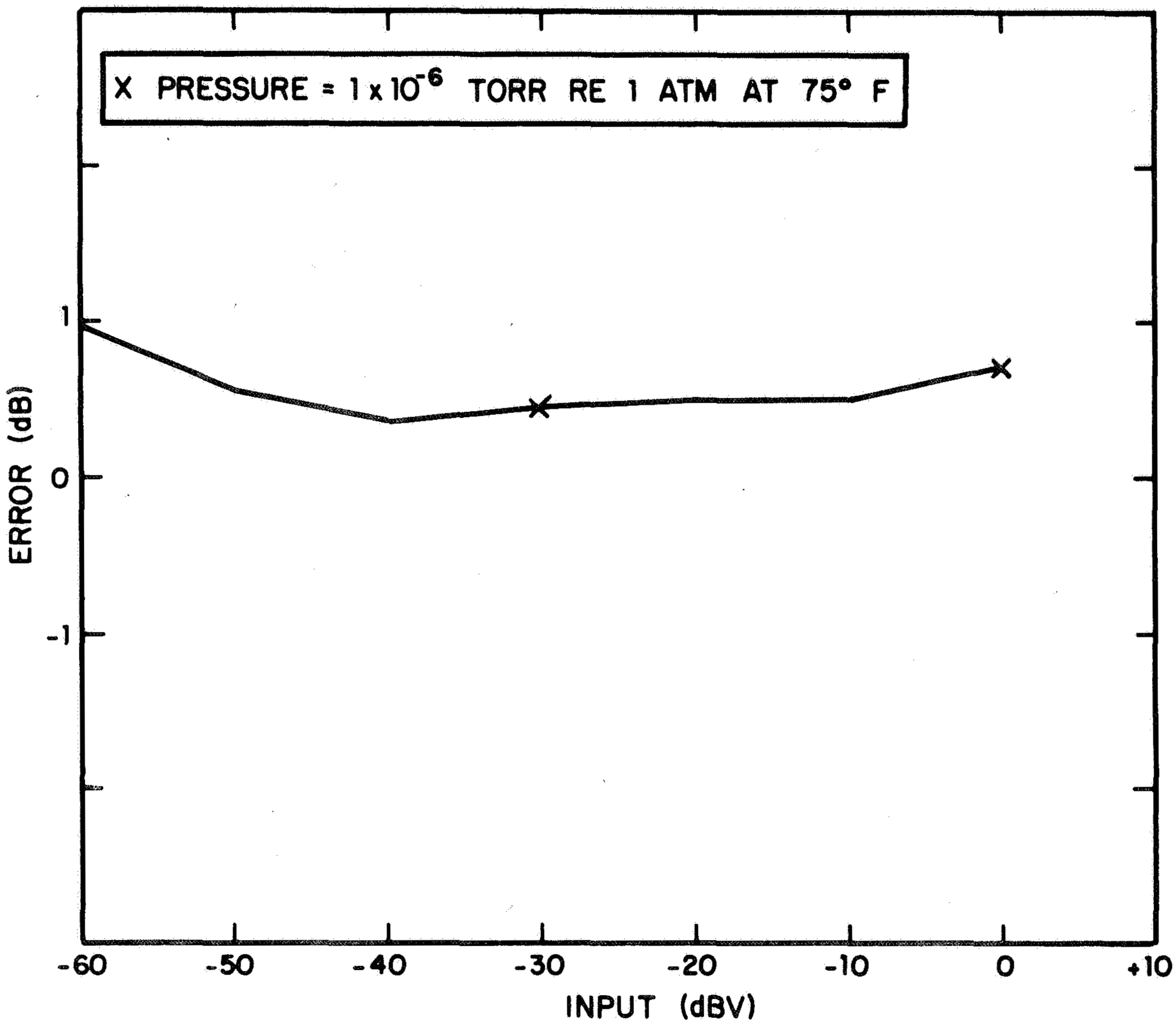


FIG. 38. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF 100 kHz CHANNEL

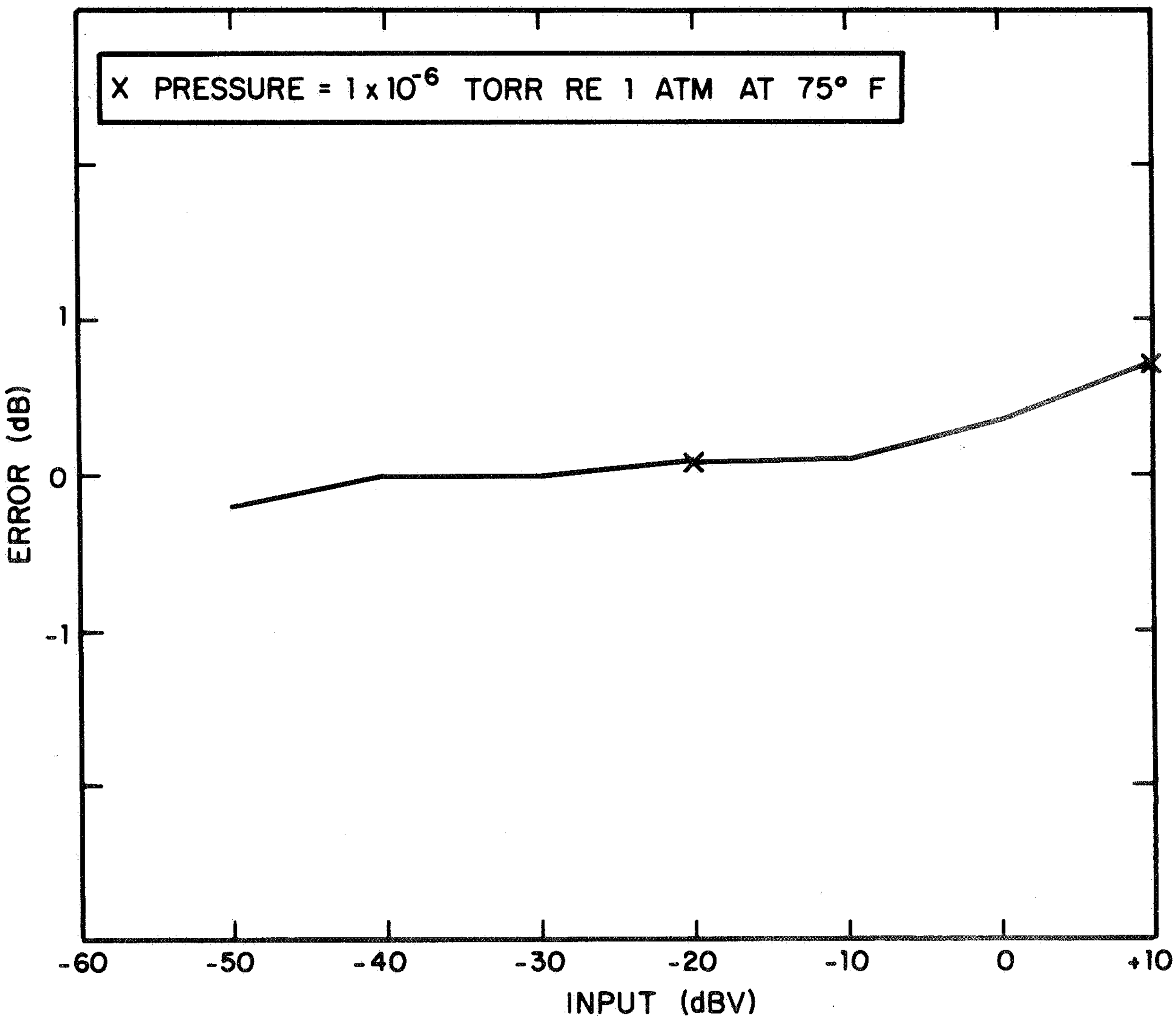


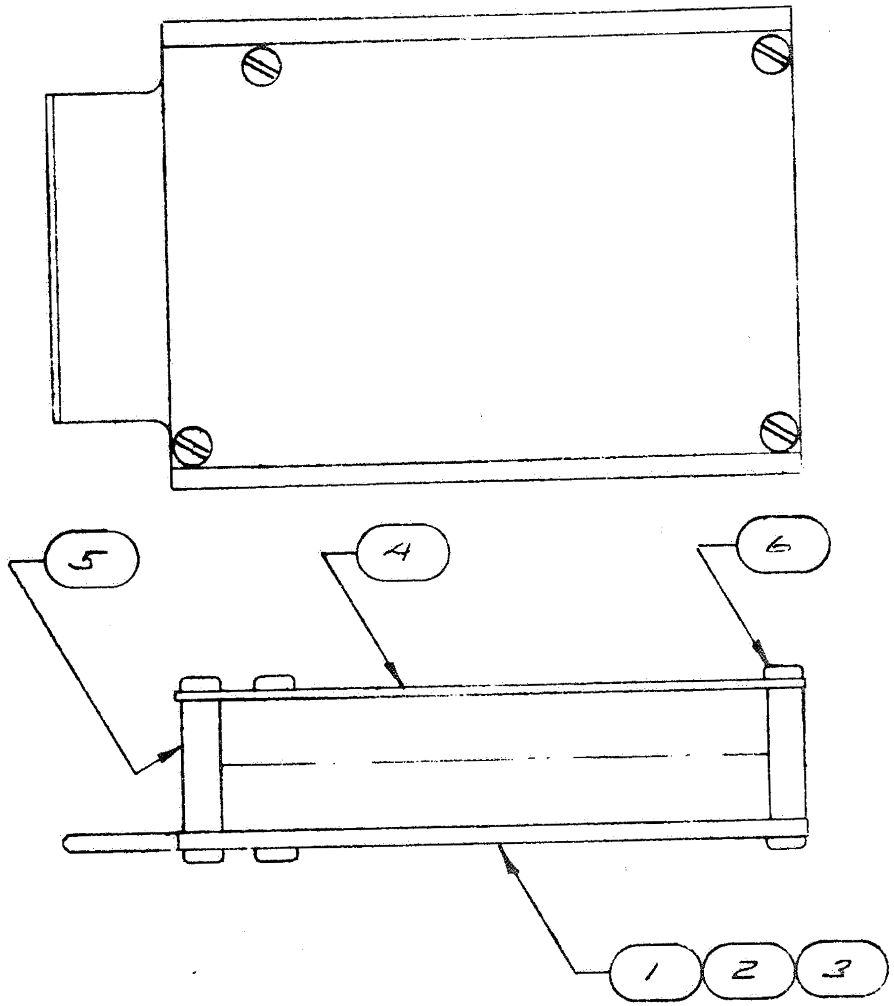
FIG. 39. SPOT VERIFICATION — LINEARITY ERROR OVER DYNAMIC RANGE OF BROADBAND DETECTOR AT 1 kHz

4. CONCLUSIONS

The design, fabrication, and test work has successfully provided a partial one-third octave band analyzer of extended signal amplitude and frequency range for use on board high-speed endo-atmospheric and space flight vehicles. The technology developed significantly reduces the requirement for wide dynamic range and wide bandwidth on telemetry links or on-board data storage equipment when dynamic pressure or vibration measurements are made.

APPENDIX A

Schematics and List of Parts

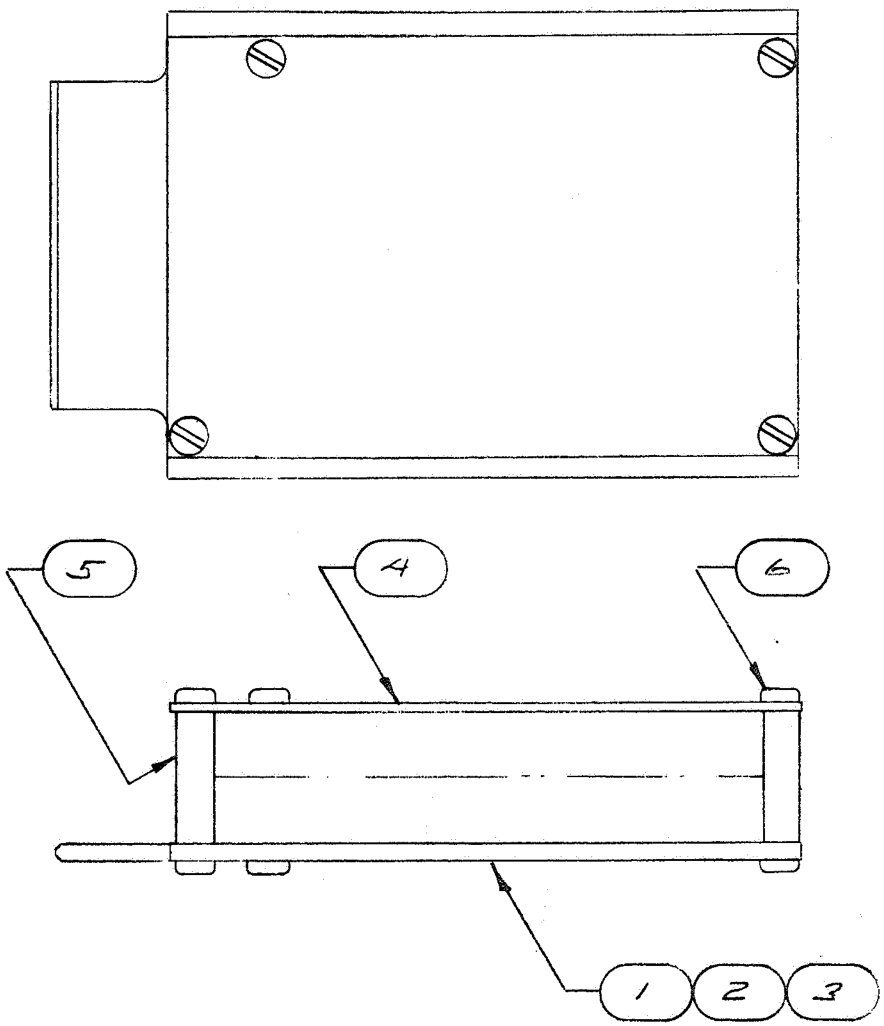


WIRE LIST			
FROM	TO	AWG	COLOR
E3	E4	24	RED
E7	E8	24	OR.
E9	E10	24	WHT.
E11	E12	24	WHT

G-1 316 HZ
G-2 1.0 KHZ
G-3 3.16 KHZ

NOTES:
1. COMPLETED ASSEMBLY EXCEPT CONNECTOR FINGERS TO BE DIPPED IN CONFORMAL COATING.

FIG. A-1. (C-20313) ANALYZER ASSEMBLY, LOW FREQUENCY

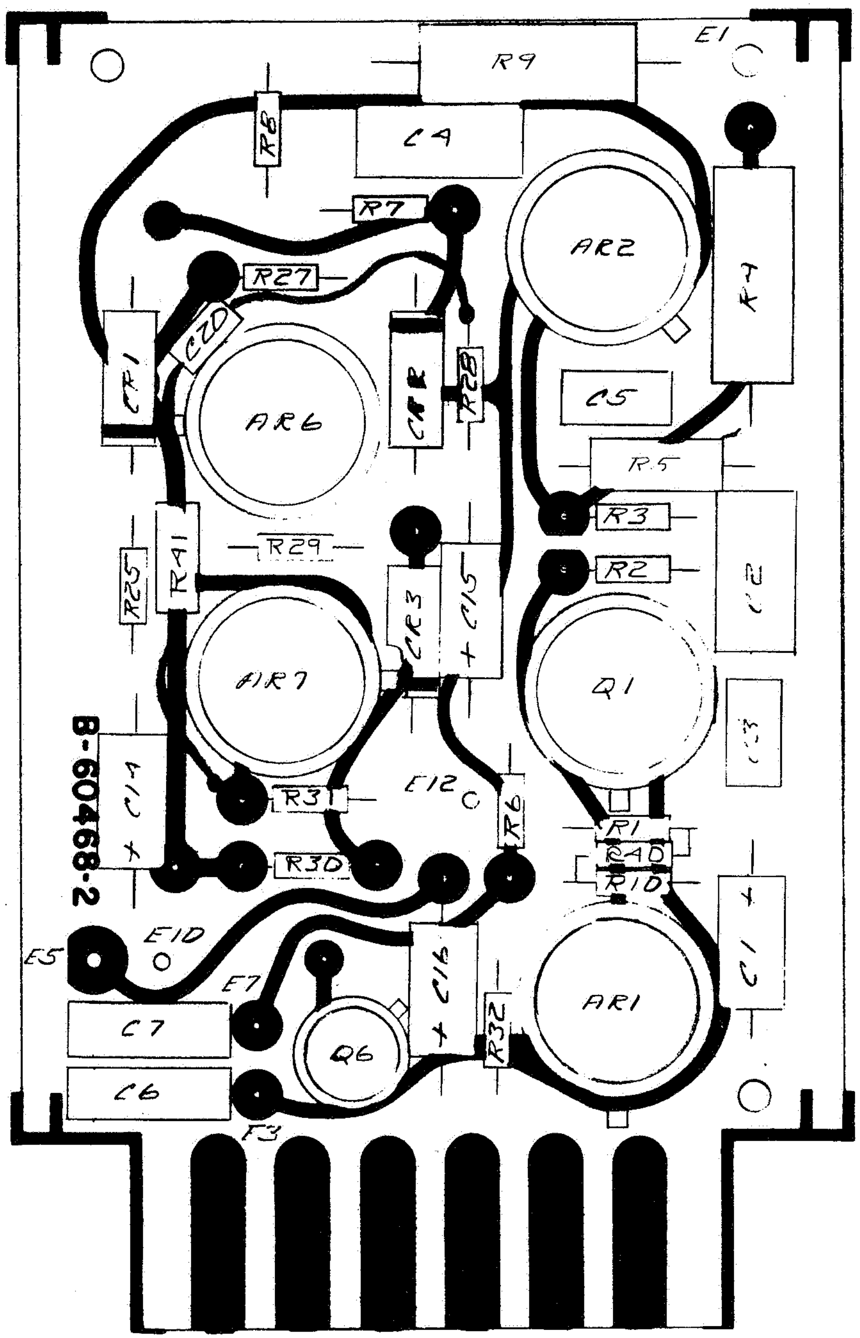


WIRE LIST			
FROM	TO	AWG	COLOR
E3	E4	24	RED
E7	E8	24	OR.
E9	E10	24	WHT
E11	E12	24	WHT

G-1 10 KHZ
G-2 31.6 KHZ
G-3 100 KHZ
G-4 BROADBAND

NOTES:
1. COMPLETED ASSEMBLY EXCEPT CONNECTOR FINGERS TO BE DIPPED IN CONFORMAL COATING.

FIG. A-2. (C-20314) ANALYZER ASSEMBLY, HIGH FREQUENCY

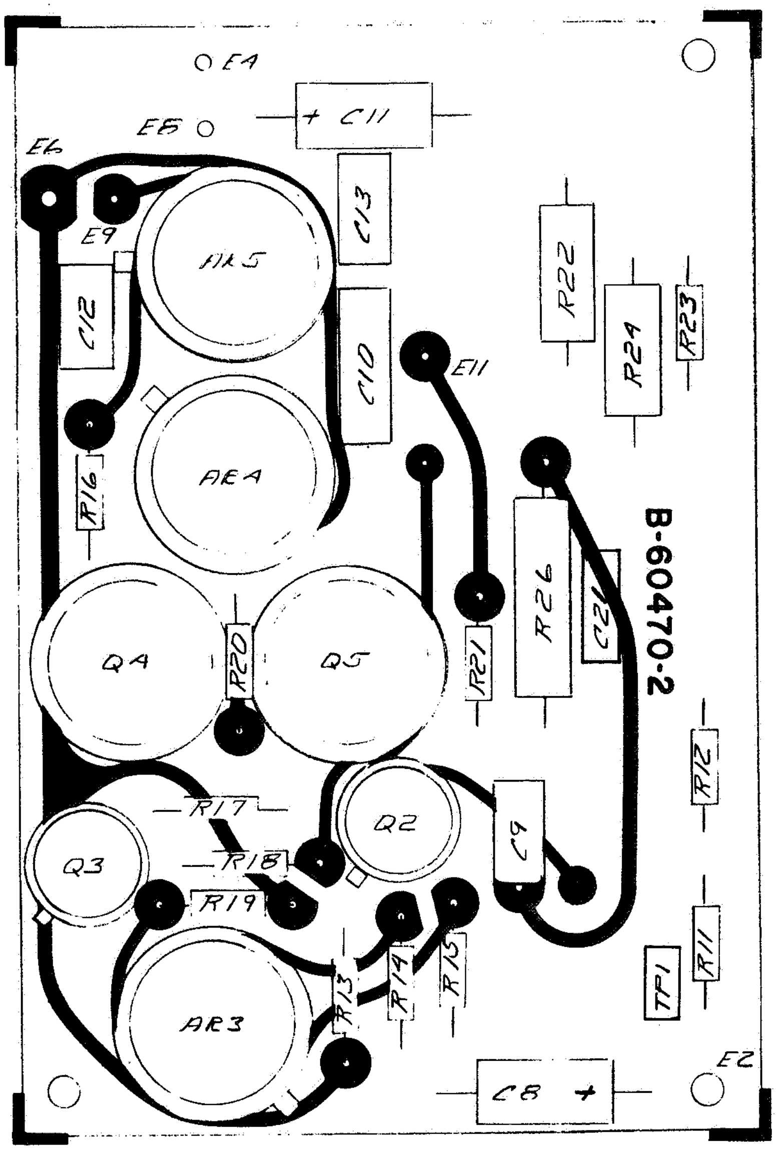


NOTES:

1. REF. D-80358
2. WARP & TWIST OF COMPLETED BOARD NOT TO EXCEED .010 IN/IN.
3. AR7 TO BE INSTALLED PRIOR TO CR3.
4. ALL COMPONENT TO BE INSTALLED AS CLOSE TO THE BOARD AS POSSIBLE WITHOUT SHORTING CIRCUITRY.

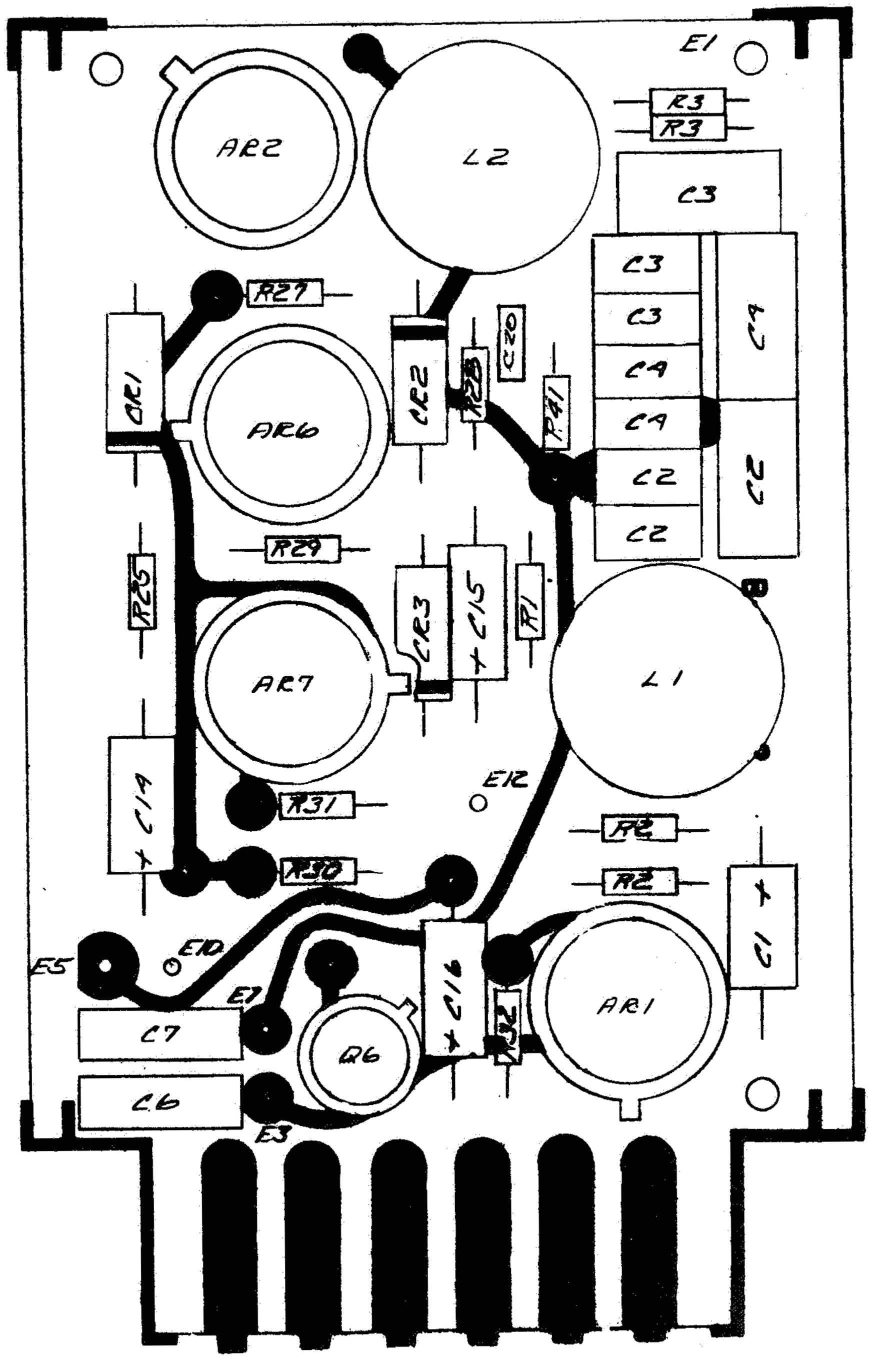
G-1	316 HZ
G-2	1.0 KHZ
G-3	3.16 KHZ

FIG. A-3. (D-60476) PRINTED CIRCUIT ASSEMBLY NO. 1



NOTES:
1. REF. D-80358
2. REF. D-80359
3. WARP & TWIST OF COMPLETED BOARD NOT TO EXCEED .010 IN/IN.
4. Q4 & Q5 TO BE INSTALLED PRIOR TO R20

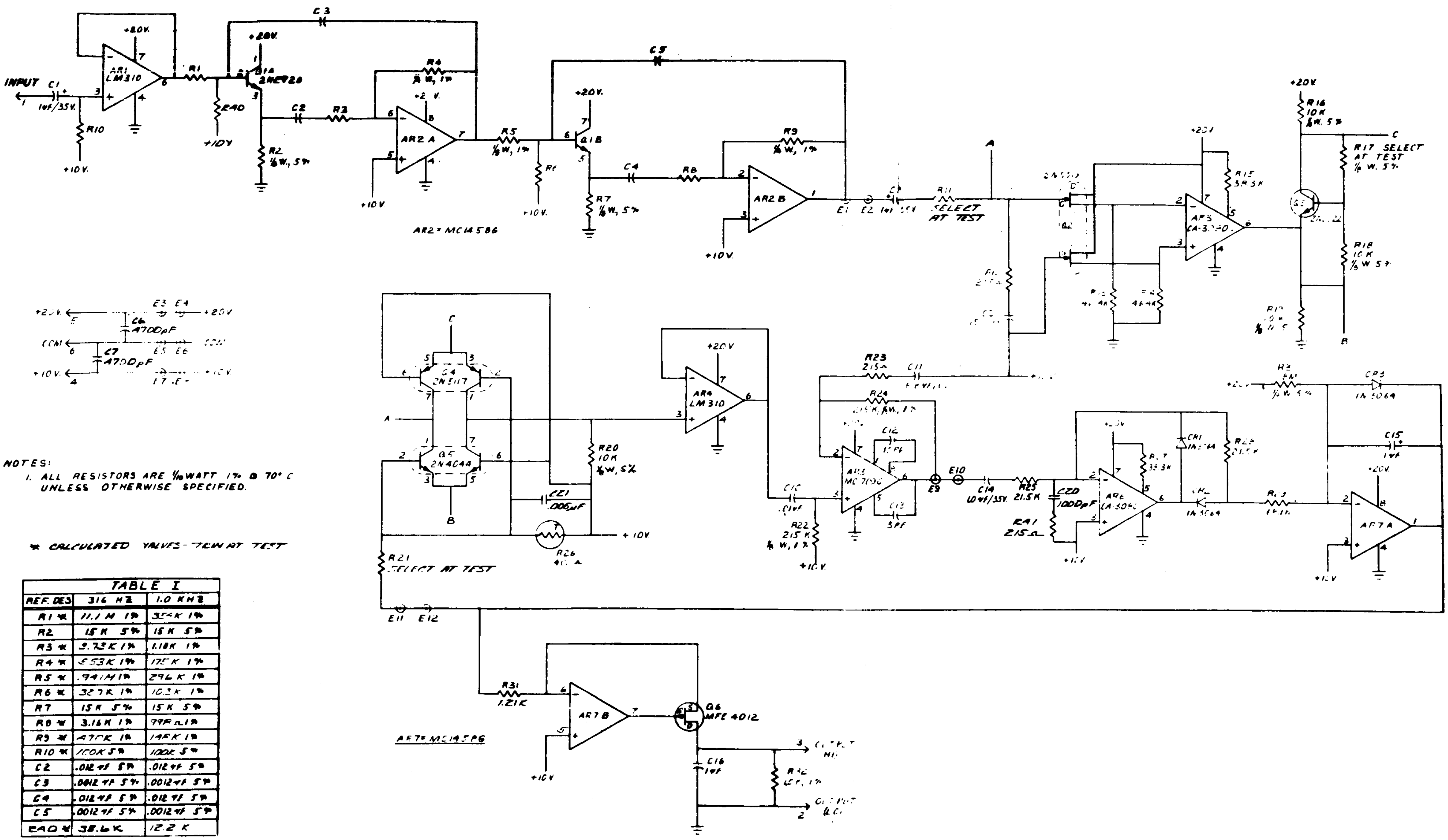
FIG. A-4. (D-60477) PRINTED CIRCUIT ASSEMBLY NO. 2



NOTES:
1. REF D-80359 G1-G3
   REF D-80367 G4
2. WARP & TWIST OF COMPLETED BOARD NOT TO EXCEED .010IN/IN
3. AR7 TO BE INSTALLED PRIOR TO CR3
4. ALL COMPONENTS TO BE INSTALLED AS CLOSE TO THE BOARD AS POSSIBLE WITHOUT SHORTING CIRCUITRY.
5. R2 IS TWO RESISTORS IN SERIES FOR G1-G3 NOT USED IN G4
6. R3 IS RESISTORS IN PARALLEL FOR G1-G5 NOT USED IN G4
7. C2 C3 & C4 ARE THREE GROUPS OF CAPACITORS WITH EACH GROUP A PARALLEL CIRCUIT OF THREE CAPACITORS FOR G1-G3 NOT USED IN G4

G-1	10 KHZ
G-2	31.6 KHZ
G-3	100 KHZ
G-4	BROAD BAND

FIG. A-5. (D-60478) PRINTED CIRCUIT ASSEMBLY NO. 3

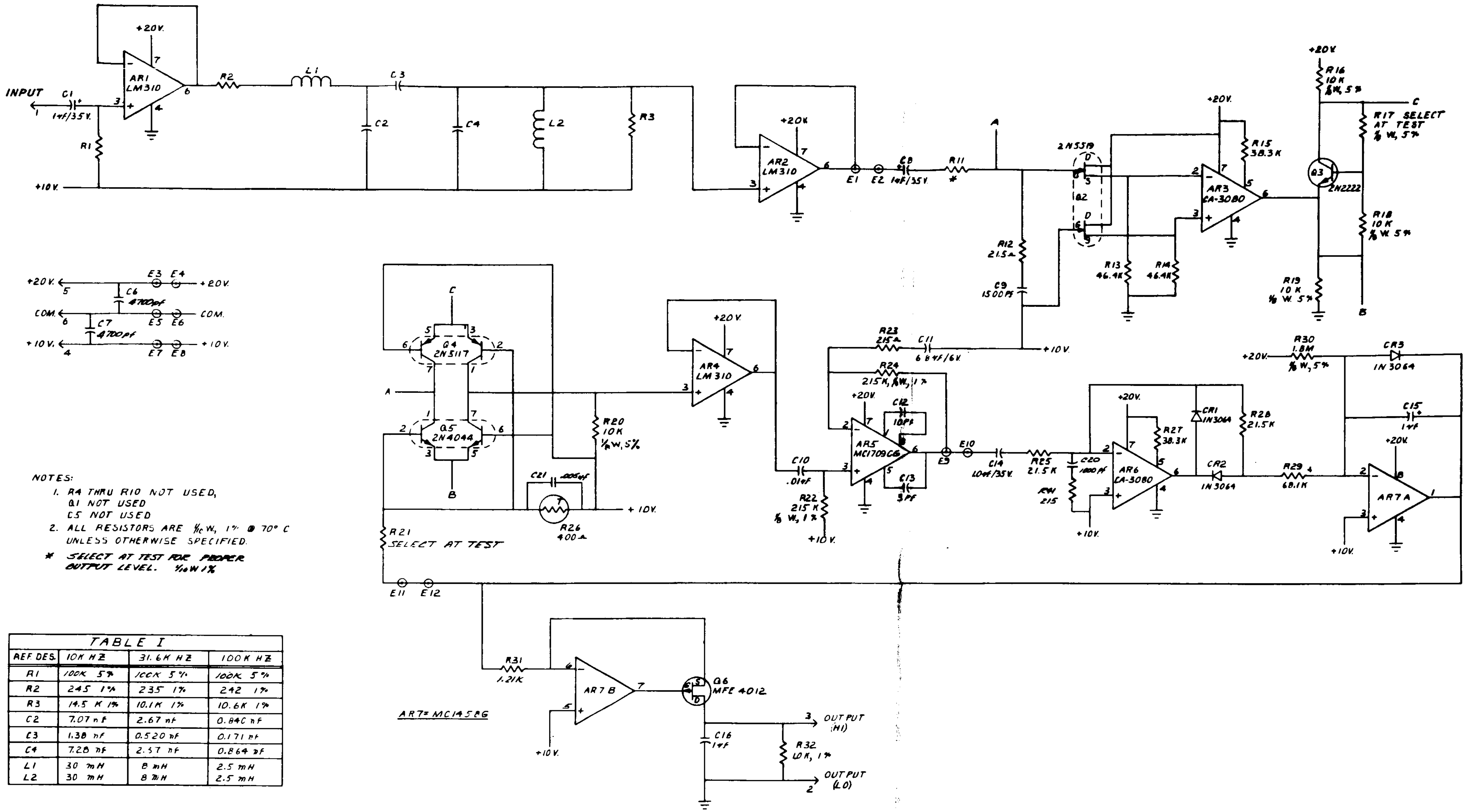


NOTES:
1. ALL RESISTORS ARE 1/10 WATT 1% @ 70° C UNLESS OTHERWISE SPECIFIED.

* CALCULATED VALUES - TRIM AT TEST

TABLE I		
REF. DES	316 HZ	1.0 KHZ
R1 *	11.1 M 1%	354K 1%
R2	15 K 5%	15 K 5%
R3 *	3.73K 1%	1.18K 1%
R4 *	553K 1%	175 K 1%
R5 *	.941 M 1%	296 K 1%
R6 *	327K 1%	10.3K 1%
R7	15 K 5%	15 K 5%
R8 *	3.16K 1%	998 Ω 1%
R9 *	470K 1%	145K 1%
R10 *	100K 5%	100K 5%
C2	.012 µF 5%	.012 µF 5%
C3	.0012 µF 5%	.0012 µF 5%
C4	.012 µF 5%	.012 µF 5%
C5	.0012 µF 5%	.0012 µF 5%
R40 *	38.6K	12.2 K

FIG. A-6. (D-80358) LOW-FREQUENCY SCHEMATIC



NOTES:

1. R4 THRU R10 NOT USED, Q1 NOT USED, C5 NOT USED
2. ALL RESISTORS ARE ⅛W, 1% @ 70° C UNLESS OTHERWISE SPECIFIED.

* SELECT AT TEST FOR PROPER OUTPUT LEVEL. ⅛W 1%

TABLE I			
REF DES.	10K HZ	31.6K HZ	100K HZ
R1	100K 5%	100K 5%	100K 5%
R2	245 1%	235 1%	242 1%
R3	14.5 K 1%	10.1K 1%	10.6K 1%
C2	7.07 nF	2.67 nF	0.840 nF
C3	1.38 nF	0.520 nF	0.171 nF
C4	7.28 nF	2.57 nF	0.864 nF
L1	30 mH	8 mH	2.5 mH
L2	30 mH	8 mH	2.5 mH

FIG. A-7. (D-80359) HIGH-FREQUENCY SCHEMATIC

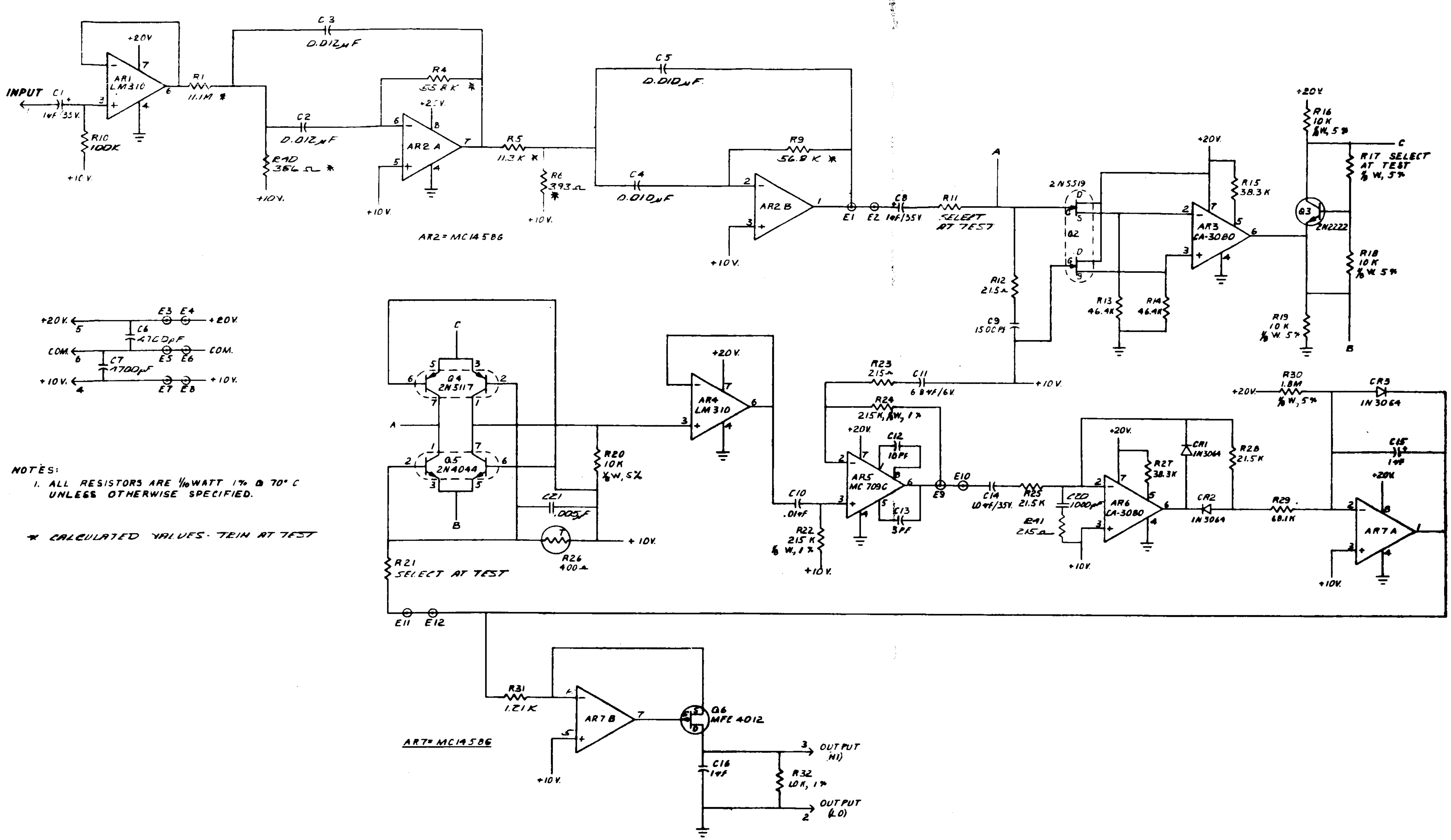


FIG. A-8. (D-80366) 3.16-kHz SCHEMATIC

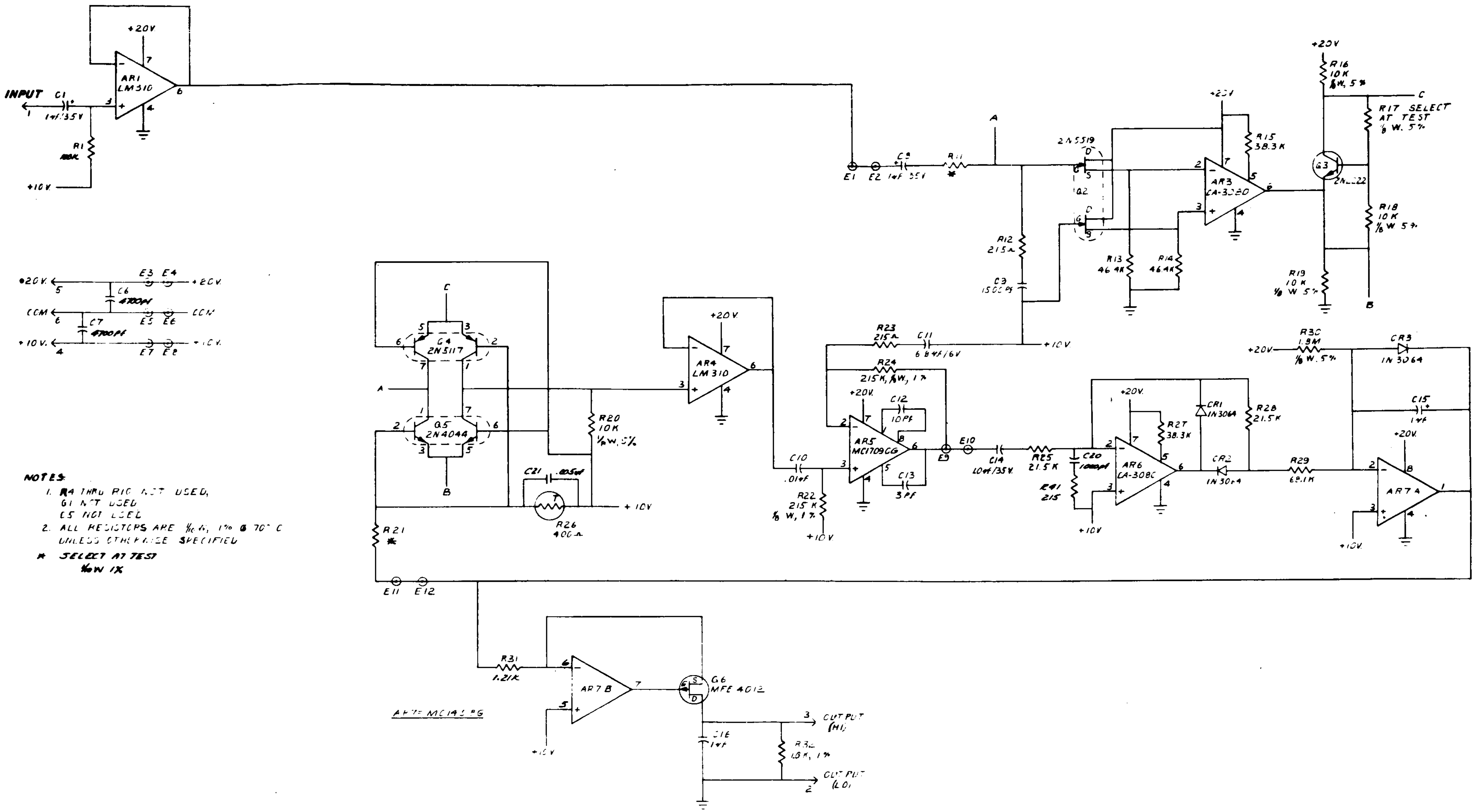


FIG. A-9. (D-80367) BROADBAND SCHEMATIC

TABLE A-1. LIST OF PARTS FOR ANALYZER ASSEMBLY, LOW FREQUENCY

ITEM NO.	DESCRIPTION	IDENTIFYING NUMBER	G-1 QTY	G-2 QTY	G-3 QTY
1	ABN. ANAL. P.C. ASS'Y No. 1	D-60476-1	1		
2	ABN. ANAL. P.C. ASS'Y No. 1	D-60476-2		1	
3	ABN. ANAL. P.C. ASS'Y No. 1	D-60476-3			1
4	ABN. ANAL. P.C. ASS'Y No. 2	D-60477	1	1	1
5	SPACER	A-31356	4	4	4
6	SCREW, MACH. PAN HD. SS	D-80×1/4 LG	8	8	8
7	ABN. 1/3 O.B. SPECT. ANAL. LOW FREQUENCY SCH.	D-80358	REF.	REF.	
8	ABN. 1/3 O.B. SPECT. ANAL. 3.16kHz SCH.	D-80366			REF.

TABLE A-2. LIST OF PARTS FOR ANALYZER ASSEMBLY, HIGH FREQUENCY

ITEM NO.	DESCRIPTION	IDENTIFYING NUMBER	G-1 QTY	G-2 QTY	G-3 QTY	G-4 QTY
1	ABN. ANAL. P.C. ASS'Y NO. 3	D-60478-1	1			
2	ABN. ANAL. P.C. ASS'Y NO. 3	D-60478-2		1		
3	ABN. ANAL. P.C. ASS'Y NO. 3	D-60478-3			1	
4	ABN. ANAL. P.C. ASS'Y NO. 2	D-60477	1	1	1	1
5	SPACER	A-31356	4	4	4	4
6	SCREW, MACH, PAN H'D. SS	D-80×1/4 LG.	8	8	8	8
7	ABN. 1/3 O.B. SPECT. ANAL. HIGH FREQUENCY SCH.	D-80359	REF.	REF.	REF.	
8	ABN. ANAL. P.C. ASS'Y NO. 3	D-60478-4				1
9	ABN 1/3 O.B. SPECT. ANAL. HIGH FREQUENCY SCH.	D-80367				REF.

TABLE A-3. LIST OF PARTS FOR PRINTED CIRCUIT ASSEMBLY NO. 1

ITEM NO.	MATERIAL AND/OR SPECIFICATION	DESCRIPTION	IDENTIFYING NUMBER	G-1 REF	G-1 QTY	G-2 REF	G-2 QTY	G-3 REF	G-3 QTY
1		ABN. ANAL. P.C. B.D. NO. 1	C-60469		1		1		1
2		RES. 38.3K, 1/10W, 1%	RN50C	R27	1	R27	1	R27	1
3		RES. 354K, 1/4W, 1%	RN50C			R1	1		
4		RES. 15K, 5%	RCR05	R2&R7	2	R2&R7	2		
5		JUMPER		R3	1				
6		RES. 1.18K, 1/10W, 1%	RN50C			R3	1		
7		RES. 562K, 1/4W, 1%	RN60C	R4	1			R4	1
8		RES. 175K, 1/4W, 1%	RN60C			R4	1		
9		RES. .941M, 1/8W, 1%	RN55C	R5	1				
10		RES. 296K, 1/8W, 1%	RN55C			R5	1		
11		RES. 35.7K, 1/10W, 1%	RN50C	R6	1			R6	1
12		RES. 10.3K, 1/10W, 1%	RN50C			R6	1	R5	1
13		RES. 3.16K, 1/10W, 1%	RN50C	R8	1				
14		RES. .998Ω 1/10W, 1%	RN50C			R8	1		
15		RES. 464K, 1/4W, 1%	RN60C	R9	1				
16		RES. 148K, 1/4W, 1%	RN60C			R9	1		
17		RES. 100K, 5%	RCR05	R10	1	R10	1	R10	1
18		RES. 21.5K, 1/10W, 1%	RN50C	R25&28	2	R25&28	2	R25&28	2
19		RES. 68.1K, 1/10W, 1%	RN50C	R29	1	R29	1	R29	1
20		RES. 1.8M, 5%	RCR05	R30	1	R30	1	R30	1
21		RES. 1.0K, 1/10W, 1%	RN50C	R32	1	R32	1	R32	1
22	SPRAGUE	CAP. 1μF/35v	150D105X9035A2	C1,14-16	4	C1,14-16	4	C1,14-16	4
23	CENTRALAB	CAP. .012μF, 5%	C37C123J	C2&4	2	C2&4	2	C2&C3	2
24	CENTRALAB	CAP. .0012μF, 5%	C37C122J	C3&5	2	C3&5	2		
25	CENTRALAB	CAP. .010μF, 5%	C37C121J					C4&C5	2
26	NATIONAL	I.C.	LM310H	AR1	1	AR1	1	AR1	1
27	MOTOROLA	I.C.	MC-1458G	AR2&7	2	AR2&7	2	AR2&7	2
28	RCA	I.C.	CA-3080	AR6	1	AR6	1	AR6	1
29	MOTOROLA	TRANSISTOR, DUAL	2N2720	Q1	1	Q1	1		
30	MOTOROLA	TRANSISTOR	MFE-4012	Q6	1	Q6	1	Q6	1
31		DIODE	IN3064	CR1-3	3	CR1-3	3	CR1-3	3
32		CAP. 4700pF		C6&7	2	C6&7	2	C6&7	2
33		RES. 11.1M		R1	1				
34		RES. 11.1K						R1	1
35		JUMPER						R3&R8	
36		RES. 393Ω						R6	1
37		RES. 56.8K						R9	1
38		RES. 38.6K		R40	1				
39		RES. 386Ω						R40	1
40		RES. 215Ω		R41	1	R41	1	R41	1
41		CAP. 1000pF		C20	1	C20	1	C20	1
42		RES. 1.21K		R31	1	R31	1	R31	1
43		RES. 12.2K				R40	1		

TABLE A-4. LIST OF PARTS FOR PRINTED CIRCUIT ASSEMBLY NO. 2

ITEM NO.	MATERIAL AND/OR SPECIFICATION	DESCRIPTION	IDENTIFYING NUMBER	REF DESIG	QTY
1		ABN ANAL. P.C. B'D NO. 2	C-6D471		1
2		RES. 10K, 1/8W, 5%	RCR05	16,18-20	4
3	CORNING	RES. 21.5 1%	C3	R12	1
4		RES. 46.4K, 1/10W, 1%	RN50C	R13&14	2
5		RES. 38.3K, 1/10W, 1%	RN50C	R15	1
6		RES. SELECT AT TEST	RCR05	R17	1
7		RES. SELECT AT TEST	RN50C	R21	1
8		RES. 215K, 1/8W, 1%	RN55C	R22&24	2
9		RES. 215, 1/10W, 1%	RN50C	R23	1
10	TEL LABS	RES. 40D TC	SA29	R26	1
11	SPRAGUE	CAP. 1µF, 35V	150D105X9035A2	C8	1
12	CENTRALABS	CAP. 1500 ρF, 5%	C37C152J	C9	1
13	CENTRALABS	CAP. .01µF, 5%	C37C103J	C10	1
14	SPRAGUE	CAP. 6.8µF/6V	150D685X9006A2	C11	1
15	CENTRALABS	CAP. 10ρF, 5%	C37C100J	C12	1
16	ELMENCO	CAP. 3µF, 0.5%	DM-10-030D	C13	1
17	SILICONIX	TRANSISTOR, DUAL	2N5519	Q2	1
18		TRANSISTOR	2N2222	Q3	1
19	HARRIS	TRANSISTOR, DUAL	2N5117	Q4	1
20	HARRIS	TRANSISTOR, DUAL	2N4044	Q5	1
21	RCA	I.C.	2A-3080	AR3	1
22	NATIONAL	I.C.	LM-310	AR4	1
23	MOTOROLA	I.C.	MC-1709CG	AR5	1
24		SELECT AT TEST	RN50C	R11	1
25		CAP. .005ut CERAMIC		C21	1
26	EF JOHNSON	TEST JACK BLACK	105-1103-001	TP1	1

TABLE A-5. LIST OF PARTS FOR PRINTED CIRCUIT ASSEMBLY NO. 3

ITEM NO.	MATERIAL AND/OR SPECIFICATION	DESCRIPTION	IDENTIFYING NUMBER	G-1 REF DESIG	G-1 QTY	G-2 REF DESIG	G-2 QTY	G-3 REF DESIG	G-3 QTY	G-4 REF DESIG	G-4 QTY
1		ABN ANAL. P.C. BOARD NO. 3	C-60473		1		1		1		1
2		RES. 100 K, 1/8W, 5%	RCR05	R1	1	R1	1	R1	1	R1	1
3	See * below	RES. 245 1/10W 1%	RN50C	R2	1					R2	
4	See * below	RES. 235 1/10W 1%	RN50C			R2	1				
5	See * below	RES. 242 1/10W 1%	RN50C					R2	1		
6	See † below	RES. 14.5K, 1/10W, 1%	RN50C	R3	1						
7	See † below	RES. 10.1K, 1/10W, 1%	RN50C			R3	1			R3	
8	See † below	RES. 10.6K, 1/10W, 1%	RN50C					R3	1		
9		RES. 21.5K, 1/10W, 1%	RN50C	R25&28	2	R25&28	2	R25&28	2	R25&28	2
10		RES. 68.1K, 1/10W, 1%	RN50C	R29	1	R29	1	R29	1	R29	1
11		RES. 1.8M 5%	RCR05	R30	1	R30	1	R30	1	R30	1
12		RES. 1.0K, 1/10W, 1%	RN50C	R32	1	R32	1	R32	1	R32	1
13	SPRAGUE	CAP. 1μF/35V.	150D105X9035A2	C1,14-16	4	C1,14-16	4	C1,14-16	4	C1,14-16	4
14	CENTRALABS	CAP. 7.07nF‡	C37 SERIES	C2	1						
15	CENTRALABS	CAP. 2.67nF‡	C37 SERIES			C2	1				
16	CENTRALABS	CAP. 0.840nF‡	C37 SERIES					C2	1		
17	CENTRALABS	CAP. 1.38nF‡	C37 SERIES	C3	1						
18	CENTRALABS	CAP. 0.520nF‡	C37 SERIES			C3	1				
19	CENTRALABS	CAP. 0.171nF‡	C37 SERIES					C3	1		
20	CENTRALABS	CAP. 7.28nF‡	C37 SERIES	C4	1						
21	CENTRALABS	CAP. 2.37nF‡	C37 SERIES			C4	1				
22	CENTRALABS	CAP. 0.864nF‡	C37 SERIES					C4	1		
23	CENTRALABS	CAP. 4700 P.F. 5%		C6&7	2	C6&7	2	C6&7	2	C6&7	2
24	NATIONAL	I.C.	LM-310	AR2	1	AR2	1	AR2	1	AR2	
25	RCA	I.C.	CA-3080	AR6	1	AR6	1	AR6	1	AR6	1
26	MOTOROLA	I.C.	MC 1458G	AR7	1	AR7	1	AR7	1	AR7	1
27	MOTOROLA	TRANSISTOR	MFE-4012	Q6	1	Q6	1	Q6	1	Q6	1
28		DIODE	IN3064	CR1-3	3	CR1-3	3	CR1-3	3	CR1-3	3
29	UTC	CHOKE 30mH	MM6	L1&2	2						
30	UTC	CHOKE 8 mH	MM3			L1&2	2				
31	UTC	CHOKE 2.5mH	MH3					L1&2	2		
32		RES 1.21K 1/10W 1%	RN50C	R31	1	R31	1	R31	1	R31	1
33		RES 215Ω 1/10W 1%	RN50C	R41	1	R41	1	R41	1	R41	1
34		CAP 1000P4 CERAMIC		C20	1	C20	1	C20	1	C20	1
35	NATIONAL	I.C.	LM-310	AR1	1	AR1	1	AR1	1	AR1	1

*R2 is two resistors in series for G1-G3 not used in G4

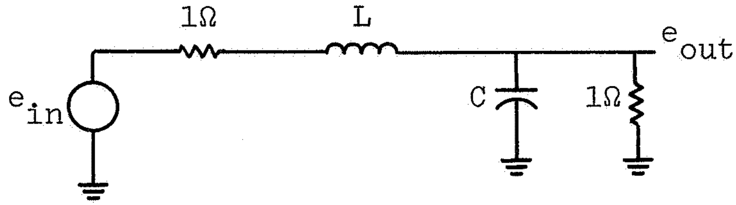
†R3 is resistors in parallel for G1-G5 not used in G4

‡C2 C3 & C4 are three groups of capacitors with each group a parallel circuit of three capacitors for G1-G3 not used in G4

APPENDIX B

Passive 1/3 Octave Band Filter Design

STEP 1. CHARACTERIZE PROTOTYPE LOW PASS FILTER

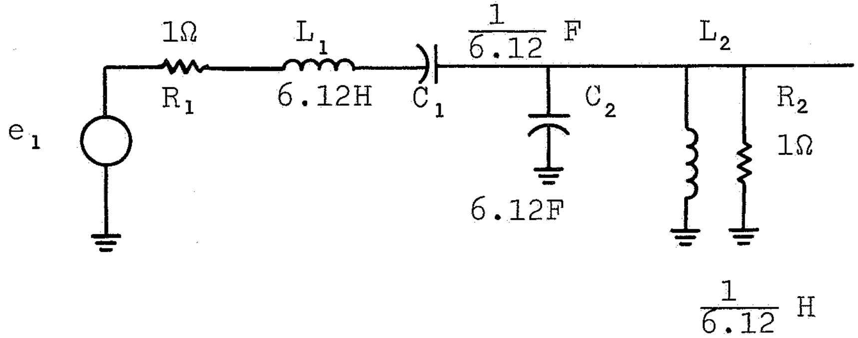


$$\frac{f_2 - f_1}{f_m} = .2316 = \frac{1}{a}$$

$$L = a\sqrt{2} = 6.12 \text{ H}$$

$$C = a\sqrt{2} = 6.12 \text{ F}$$

STEP 2. TRANSFORM TO NORMALIZED BAND PASS FILTER

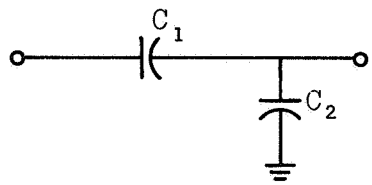


Note: L_1C_1 and L_2C_2 each resonate at 1 $\frac{\text{Radian}}{\text{Sec}}$

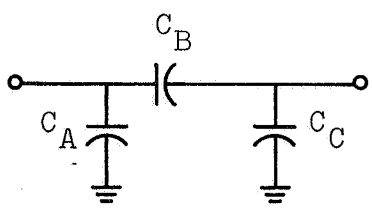
Problem! $\frac{L_1}{L_2} \simeq 37$ which is most inconvenient since we want to use stock inductors.

STEP 3. IMPEDANCE TRANSFORM PORTION OF CIRCUIT AROUND L_2 IN ORDER TO REALIZE DESIRED L_1/L_2*

Choose $\frac{L_1}{L_2} = 1$ so $L_1 = L_2 = 6.12H$

Replace 

With



Where $C_A = (1-n)C_1$

$C_B = n_1 C_1$

$C_C = n^2(C_1+C_2)-nC_1$

$$n = \frac{1}{6.12}$$

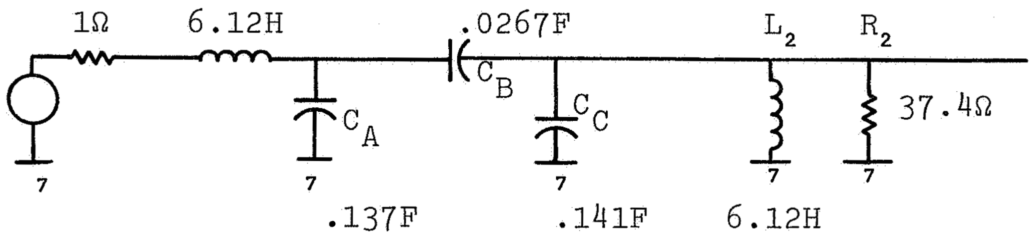
$$C_A = \left(1-\frac{1}{6.12}\right)\frac{1}{6.12} = .137F$$

$$C_B = \frac{1}{6.12} \cdot \frac{1}{6.12} = .0267F$$

$$C_C = \left(\frac{1}{6.12}\right)^2\left(\frac{1}{6.12} + 6.12\right) - \frac{1}{6.12}\times\frac{1}{6.12} = .141F$$

*Guillemin, E.A., "Synthesis of Passive Networks," John Wiley & Sons, New York, 1957, pp. 141-157.

STEP 4. COMPLETE THE IMPEDANCE TRANSFORMATION STARTED IN STEP 3 TO REALIZE THE PROTOTYPE BAND PASS FILTER



This is a 1/3 OB filter with a center frequency of 1 Radian/Sec and terminating resistances of 1 ohm and 37.4 ohms respectively.

STEP 5. SCALE THE PROTOTYPE TO THE DESIRED FREQUENCY AND IMPEDANCE LEVELS

$\omega_m = 2\pi f_m$ (mid band frequency)

$R_1 = \dfrac{\omega_m L_1}{6.12}$ $R_2 = 37.4\ R_1$

$L_D = \dfrac{L_1}{6.12}$

$C_D = \dfrac{1}{L_D \omega_m^2}$

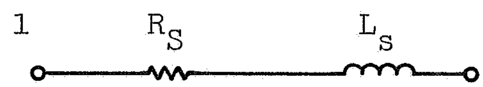
$C_A = 0.137\ C_D$

$C_B = 0.267\ C_D$

$C_C = 0.141\ C_D$

STEP 6. CORRECT THE RESULTS OF STEP 5 FOR THE LOSSES IN THE INDUCTORS

Series Equivalent Circuit

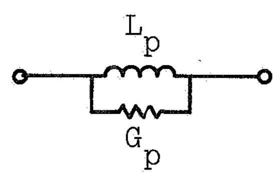


$$R_S = \frac{\omega_m L}{Q}$$

Curves of Q vs frequency are given in data sheet for inductors.

Similarly,

Parallel Equivalent Circuit



$$G_p = \frac{1}{Q\omega_m L}$$

$$L \cong L_p \cong L_S \quad \text{for } Q>>1$$

so

$$R_1' = R_1 - R_S$$

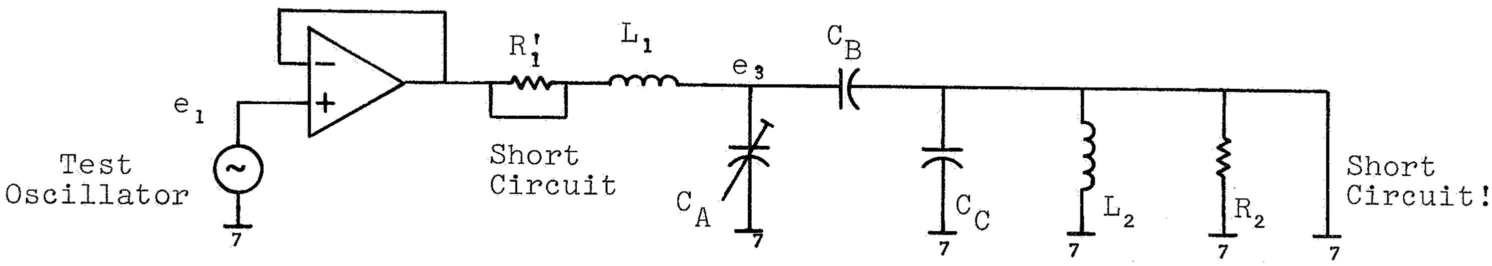
$$R_2' = \frac{1}{\left[\frac{1}{R_2} - G_p\right]}$$

f_m	$L_1=L_2$	Q_L	C_A	C_B	C_C	R_1	R_2	R'_1	R'_2
10kHz	30mH	30	7.07nF	1.38nF	7.28nF	308	11.5k	245	14.5k
12.5kHz									
16kHz									
20kHz									
25kHz									
31.5kHz	8mH	60	2.63nF	512pf	2.71nF	260	9.74k		
40kHz									
50kHz									
63kHz									
80kHz									
100kHz	2.5mH								

STEP 7. TUNING ACTUAL FILTER

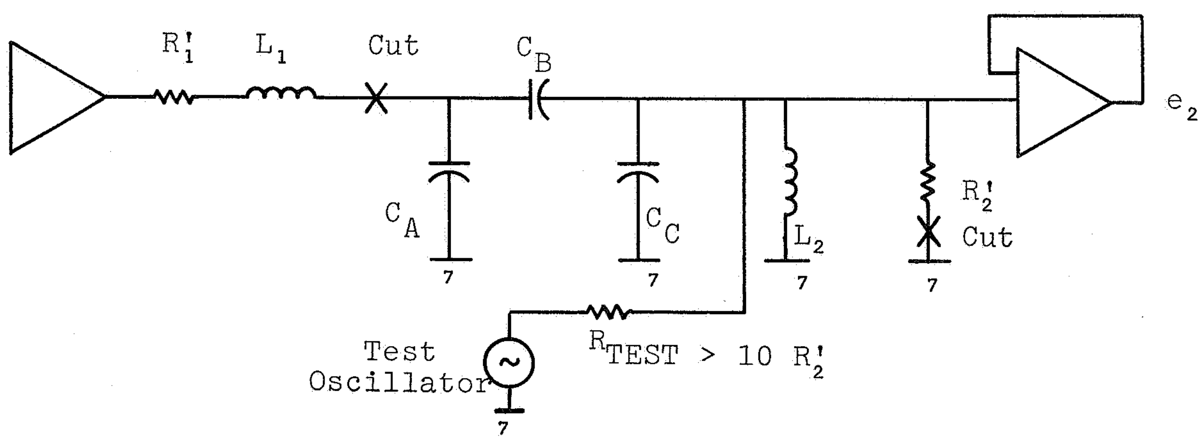
Because of component tolerances, C_A and C_C will have to be tuned in the actual circuit as follows (C_B should be within 5% of correct value and doesn't need trimming).

To trim C_A use the following circuit:



Observe e_3 with low capacitance probe. Trim C_A so resonant peak is at f_m. Note this is actual circuit plus two jumpers.

To trim C_C use the following circuit:



Observe e_2 and trim C_C so resonant peak is at f_m. Note this is actual circuit with two cuts plus one external resistor.

APPENDIX C

Pertinent Data from the American Standard Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets.

S1.11-1966

Sponsored by the Acoustical Society of America

Approved May 4, 1966
American Standards Association Incorporated

1. Purpose and Scope

1.1 Purpose. The purpose of this standard for filter sets is to specify particular bandwidths and characteristics which may be used to ensure that all analyses of noise will be consistent within known tolerances when made with similar filter sets meeting these specifications.

1.2 Scope. The standard for filter sets is suited to the requirements for analyzing, as a function of frequency, a broadband electrical signal. For acoustical measurements an electro-acoustic-transducer and amplifier are employed to convert the acoustic signal to be analyzed into the required electrical signal.

2. Definitions

These definitions are based upon those given in American Standard Acoustical Terminology (Including Mechanical Shock and Vibration), S1.1-1960.

2.1 Wave Filter (Filter). A wave filter is a transducer for separating waves on the basis of their frequency. It introduces relatively small insertion loss to waves in one or more frequency bands, and relatively large insertion loss to waves of other frequencies. (See 6.12 of American Standard S1.1-1960.)

2.2 Band-Pass Filter. A band-pass filter is a wave filter that has a single transmission band extending from a lower band-edge frequency greater than zero to a finite upper band-edge frequency.

NOTE: This definition is identical to the definition in 6.15 of American Standard S1.1-1960 except that the words "band-edge frequency" are substituted for "cutoff frequency." Cutoff frequency in 6.16 of American Standard S1.1-1960 is restricted to a frequency at which the response is 3 dB below the maximum response. In this standard the restriction does not apply to the frequencies limiting the passband. Therefore, the term "band-edge frequency" is used to avoid confusion. See 3.3 and Appendix B.

2.3 Filter Bandwidth. The bandwidth of a filter is the difference between the upper and lower band-edge frequencies, and defines the transmission band or pass band. In this specification the bandwidth is described by the interval in octaves between the upper and lower band-edge frequencies.

2.4 Spectrum. The spectrum of a function of time is a description of its resolution into components, each of a different frequency and (usually) different in amplitude and phase. [See 1.34 (1) of American Standard S1.1-1960.] A *Continuous Spectrum* is the spectrum of a wave the components of which are continuously distributed over a frequency region. (See 1.37 of American Standard S1.1-1960.) A *White Noise Spectrum* is a continuous spectrum whose spectrum density (mean-square amplitude per unit frequency) is independent of frequency over a specified frequency range.

2.5 Transmission Loss. Transmission Loss is the reduction in the magnitude of some characteristic of a signal, between two stated points in a transmission system. (See 4.29 of American Standard S1.1-1960.)

NOTE 1: In this specification the *Transmission Loss* is the reduction in power level or voltage level between the input applied to the filter in series with its proper input terminating impedance, and the output delivered by the filter to its proper load impedance.

NOTE 2: In this specification the *Transmission Loss Characteristic* of a filter, representing the change of Transmission Loss with frequency, is specified with respect to the minimum Transmission Loss in the passband measured when the filter is inserted between the proper terminating impedances.

NOTE 3: *Attenuation* (not defined in American Standard S1.1-1960) is frequently used as synonymous with Transmission Loss as defined above, in connection with filter characteristics.

NOTE 4: *Insertion Loss* is a term also frequently used in connection with filters. The Insertion Loss resulting from insertion of a transducer in a transmission system is 10 times the logarithm to the base 10 of the power delivered to that part of the system that will follow the transducer, before insertion of the transducer, to the power delivered to that same part of the system after insertion of the transducer. (See 7.2 of American Standard S1.1-1960.) For passive filters operated between resistive terminating impedances, the *Insertion Loss Characteristic* employing the minimum value as referent is the same as the *Transmission Loss Characteristic.*

2.6 Terminating Impedances. The terminating impedances are the impedances of the external input and output circuits between which the filter is connected.

2.7 Peak-to-Valley Ripple. When the transmission loss characteristic in the transmission band contains a series of maxima and minima, or ripples, the peak-to-valley ripple is defined as the difference in decibels between the extremes of minimum and maximum transmission loss in the pass band region.

3. Requirements

3.1 Filter Sets. The filter set shall provide a number of filter bands according to the schedules listed in Table 1, and shall bear the corresponding Type symbol:

R for Restricted Range
E for Extended Range
O for Optional Range

The filter bands are identified by the designation mean frequency f_m of the band as defined in 3.2.

3.2 Nominal Mean Frequency, f_m

3.2.1 ***Band Designation Frequencies.*** The values of mean frequency, f_m, used for band designation in Table 1 are based upon the recommendations of 5.2, page 3, of American Standard S1.6-1960. Band designation frequencies shall be rounded according to American Standard S1.6-1960.

3.2.2 ***Precise Values of f_m.*** Precise values of nominal mean frequency f_m shall be calculated from the formulas given in Table 2.

3.3 Nominal Frequency Bandwidths. The nominal band-edge frequencies and bandwidths for the octave, half-octave, and third-octave band filters are defined by the relations given in Table 3. The frequency f_m in each band is the geometric mean of the upper and lower nominal band-edge frequencies, f_1 and f_2, which are defined by Table 3.

3.4 Transmission Loss vs Frequency Characteristics of Individual Filters. When tested as specified in Section 4, the separate filters of a set shall conform to the requirements in the paragraphs below. For each filter characteristic, transmission loss is specified with respect to the minimum transmission loss in the frequency range f_1 to f_2 delineated in Table 3. Transmission loss characteristics are grouped under three classes (I, II, or III) depending upon the steepness of the slope of the transmission loss vs frequency curve. Filter designations must bear the appropriate Class symbol.

NOTE: In the transmission loss characteristics specified below, the mathematical statement is the governing consideration. The graphical representation accompanying each characteristic requirement is added for convenience. The actual filter characteristic, in addition to falling within the transmission loss limits shown, must simultaneously meet the requirements on *Passband Uniformity* (see 3.6) and on *Effective Bandwidth* (see 3.7). On each plot a dotted curve is shown as an example of a characteristic meeting all requirements.

Table 1
Table of Filter Bands To Be Provided

Band Number	Mean Frequency f_m (c/s)	Octave Bands		Half-Octave Bands		Third-Octave Bands		Any Band
		Type R	Type E	Type R	Type E	Type R	Type E	Type O
14	25						x	Filter Bands as Specified by the Manufacturer
15	31.5		x		x		x	
16	40						x	
16.5	45				x			
17	50						x	
18	63		x		x		x	
19	80						x	
19.5	90				x			
20	100					x	x	
21	125	x	x	x	x	x	x	
22	160					x	x	
22.5	180			x	x			
23	200					x	x	
24	250	x	x	x	x	x	x	
25	315					x	x	
25.5	355			x	x			
26	400					x	x	
27	500	x	x	x	x	x	x	
28	630					x	x	
28.5	710			x	x			
29	800					x	x	
30	1000	x	x	x	x	x	x	
31	1250					x	x	
31.5	1400			x	x			
32	1600					x	x	
33	2000	x	x	x	x	x	x	
34	2500					x	x	
34.5	2800			x	x			
35	3150					x	x	
36	4000	x	x	x	x	x	x	
37	5000					x	x	
37.5	5600				x			
38	6300						x	
39	8000		x		x		x	
40	10000						x	
40.5	11200				x			
41	12500						x	
42	16000						x	
43	20000						x	

Table 2
Nominal Mean Frequencies, f_m

Octave Bands	$f_m = 10^{3n/10}$
Half-Octave Bands	$f_m = 10^{3n/20}$
Third-Octave Bands	$f_m = 10^{3n/30}$

NOTE: n is any integer, positive, negative, or zero.

Table 3
Nominal Band-Edge Frequencies and Frequency Bandwidths

	Octave Band	Half-Octave Band	Third-Octave Band
Formula	$f_1 = 2^{-1/2} f_m$	$f_1 = 2^{-1/4} f_m$	$f_1 = 2^{-1/6} f_m$
	$f_2 = 2^{1/2} f_m$	$f_2 = 2^{1/4} f_m$	$f_2 = 2^{1/6} f_m$
Numerical Value	$f_1 = 0.7071 f_m$	$f_1 = 0.8409 f_m$	$f_1 = 0.8909 f_m$
	$f_2 = 1.4142 f_m$	$f_2 = 1.1892 f_m$	$f_2 = 1.1225 f_m$
Bandwidth $f_2 - f_1$	$0.7071 f_m$	$0.3483 f_m$	$0.2316 f_m$

f_1 = nominal lower band-edge frequency
f_2 = nominal upper band-edge frequency
f_m = calculated from formulas of Table 2

3.4.1 ***Octave Band Filters — Class I***

(1) At any frequency, f, in the range from $\frac{3f_m}{4}$ to $\frac{4f_m}{3}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{8}{5} \left[1 + 3\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^2\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{5}$ to $\frac{f_m}{\sqrt{2}}$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{1}{8}\left(\frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, in the range from $\frac{f_m}{10}$ to $\frac{f_m}{5}$ the transmission loss shall be more than

$$10 \log_{10} \left[1 + \frac{25}{8}\left(\frac{f}{f_m}\right)^4\right] \text{ decibels.}$$

(4) At any frequency, f, in the range from $\sqrt{2} f_m$ to $5f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[\frac{1}{8}\left(\frac{f}{f_m}\right)^6\right] \text{ decibels.}$$

(5) At any frequency, f, in the range from $5f_m$ to $10f_m$ the transmission loss shall be more than

$$10 \log_{10} \left[1 + \frac{25}{8}\left(\frac{f}{f_m}\right)^4\right] \text{ decibels.}$$

(6) At any frequency, f, below $\frac{f_m}{10}$ or above $10f_m$ the transmission loss shall be more than 45 decibels.

(7) A graphical representation of the allowable limits is given in Fig. 1.

3.4.2 ***Octave Band Filters — Class II***

(1) At any frequency, f, in the range from $\frac{3f_m}{4}$ to $\frac{4f_m}{3}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 30\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{8}$ to $\frac{f_m}{\sqrt{2}}$ and from $\sqrt{2} f_m$ to $8f_m$ the transmission loss shall be more than

$$10 \log_{10} \frac{2}{3} \left[1 + 4\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{8}$ or above $8f_m$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 2.

3.4.3 ***Half-Octave Band Filters — Class II***

(1) At any frequency, f, in the range from $\frac{6f_m}{7}$ to $\frac{7f_m}{6}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 200\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{9f_m}{100}$ to $2^{-1/4} f_m$ and from $2^{1/4} f_m$ to $\frac{100f_m}{9}$ the transmission loss shall be more than

$$10 \log_{10} \left[68\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{9f_m}{100}$ or above $\frac{100f_m}{9}$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 3.

3.4.4 ***Half-Octave Band Filters — Class III***

(1) At any frequency, f, in the range from $\frac{6f_m}{7}$ to $\frac{7f_m}{6}$ the transmission loss shall not be more than

$$10 \log_{10} \frac{5}{4} \left[1 + 200\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

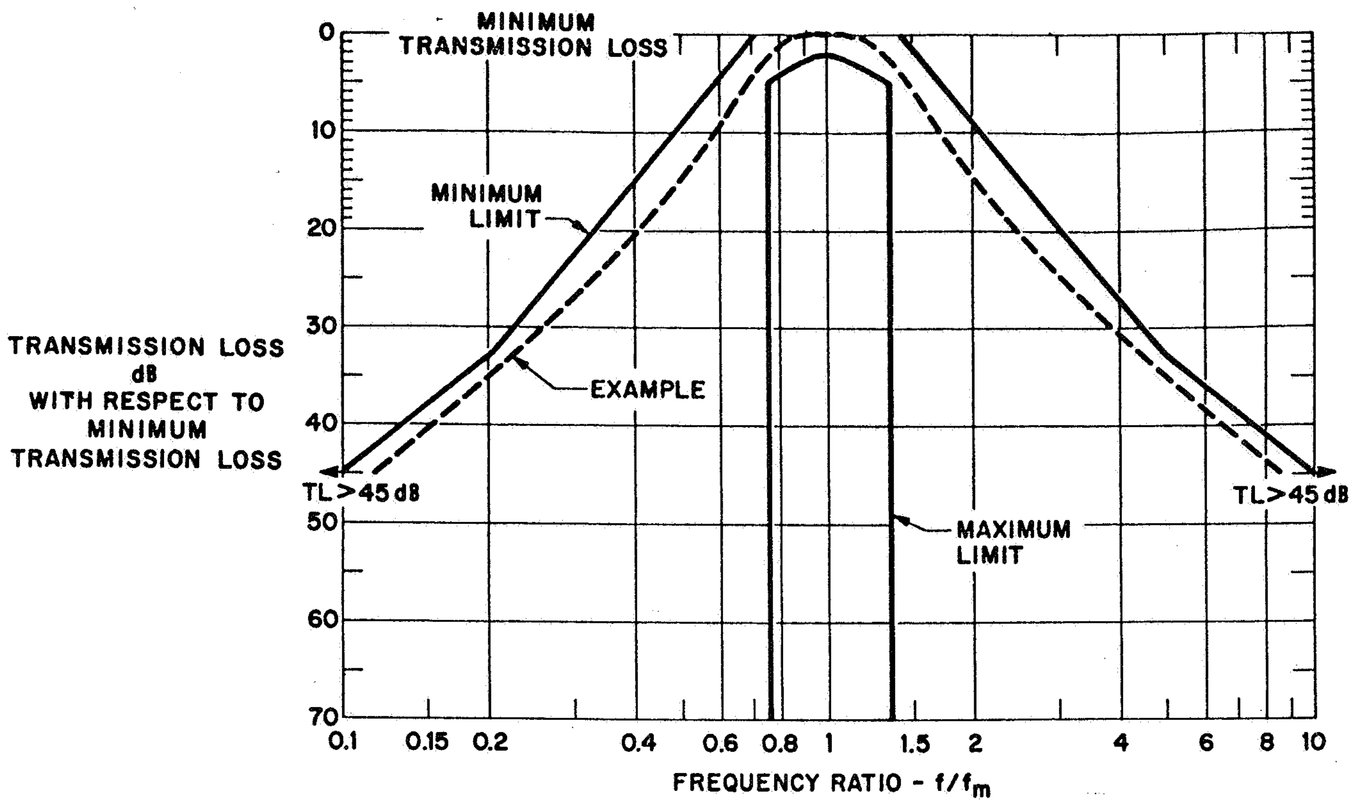


Fig. 1

Transmission Loss Limits — Octave Band Filter, Class I

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

(2) At any frequency, f, in the range from $\frac{f_m}{6}$ to $2^{-1/4}f_m$ and from $2^{1/4}f_m$ to $6f_m$ the transmission loss shall be more than

$$10 \log_{10}\left[\frac{5}{9} + 250\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{6}$ or above $6f_m$ the transmission loss shall be more than 70 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 4.

3.4.5 *Third-Octave Band Filters — Class II*

(1) At any frequency, f, in the range from $\frac{9f_m}{10}$ to $\frac{10f_m}{9}$ the transmission loss shall not be more than

$$10 \log_{10}\frac{5}{4}\left[1 + 1040\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{8}$ to $2^{-1/6}f_m$ and from $2^{1/6}f_m$ to $8f_m$ the transmission loss shall be more than

$$10 \log_{10}\frac{1}{4}\left[1 + 1040\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{8}$ or above $8f_m$ the transmission loss shall be more than 60 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 5.

3.4.6 *Third-Octave Band Filters — Class III*

(1) At any frequency, f, in the range from $\frac{9f_m}{10}$ to $\frac{10f_m}{9}$ the transmission loss shall not be more than

$$10 \log_{10}\frac{5}{4}\left[1 + 1040\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^4\right] \text{ decibels.}$$

(2) At any frequency, f, in the range from $\frac{f_m}{5}$ to $2^{-1/6}f_m$ and from $2^{1/6}f_m$ to $5f_m$ the transmission loss shall be more than

$$10 \log_{10}\left[\frac{8}{13} + 2500\left(\frac{f}{f_m} - \frac{f_m}{f}\right)^6\right] \text{ decibels.}$$

(3) At any frequency, f, below $\frac{f_m}{5}$ or above $5f_m$ the transmission loss shall be more than 75 decibels.

(4) A graphical representation of the allowable limits is given in Fig. 6.

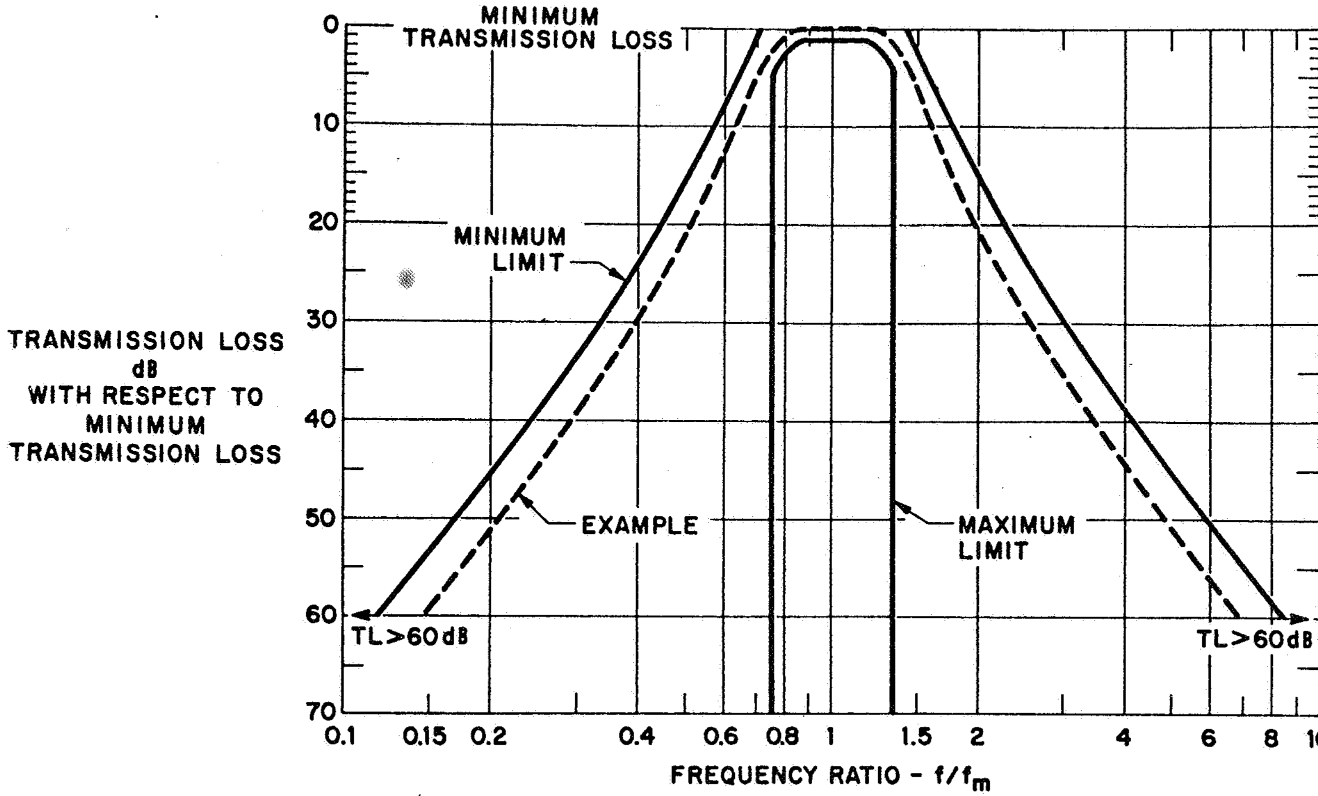


Fig. 2

Transmission Loss Limits — Octave Band Filter, Class II

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

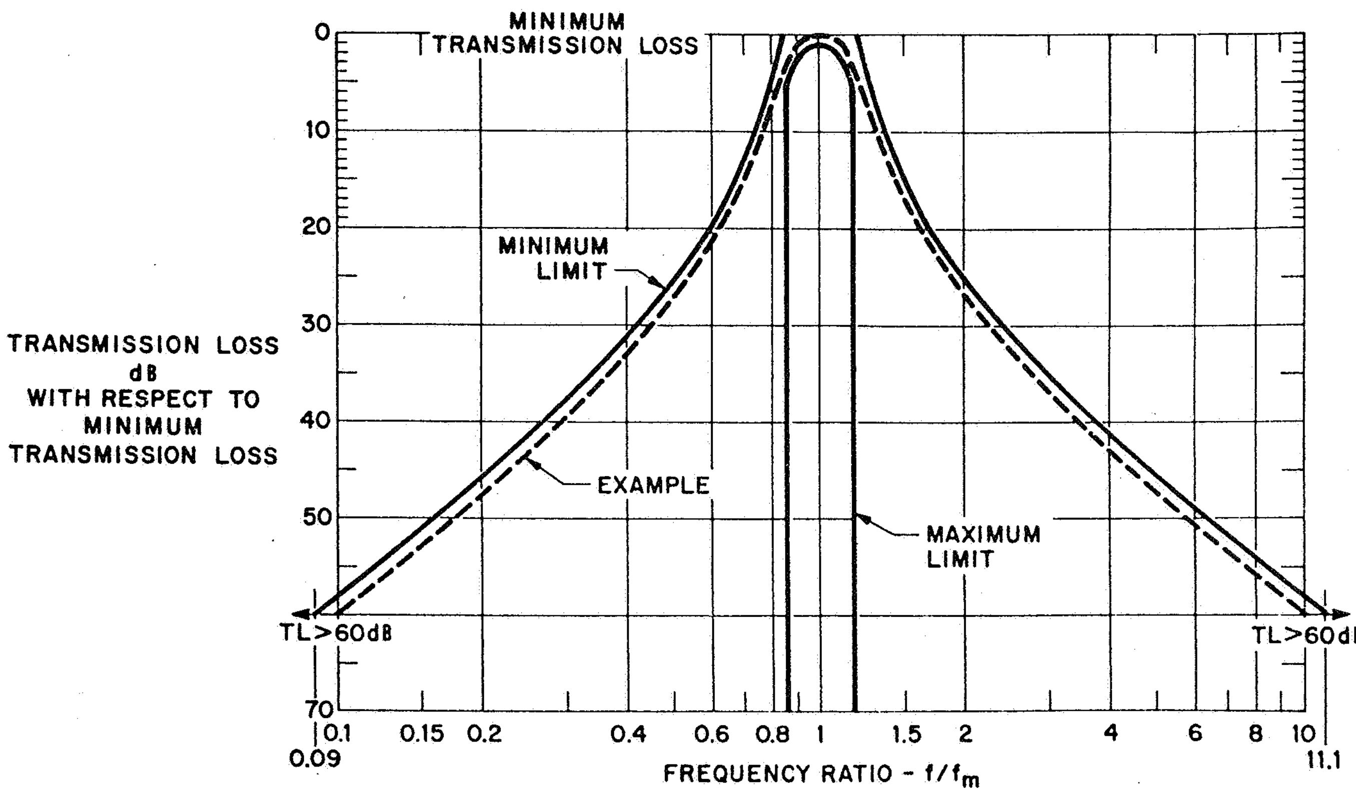


Fig. 3

Transmission Loss Limits — Half-Octave Band Filter, Class II

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

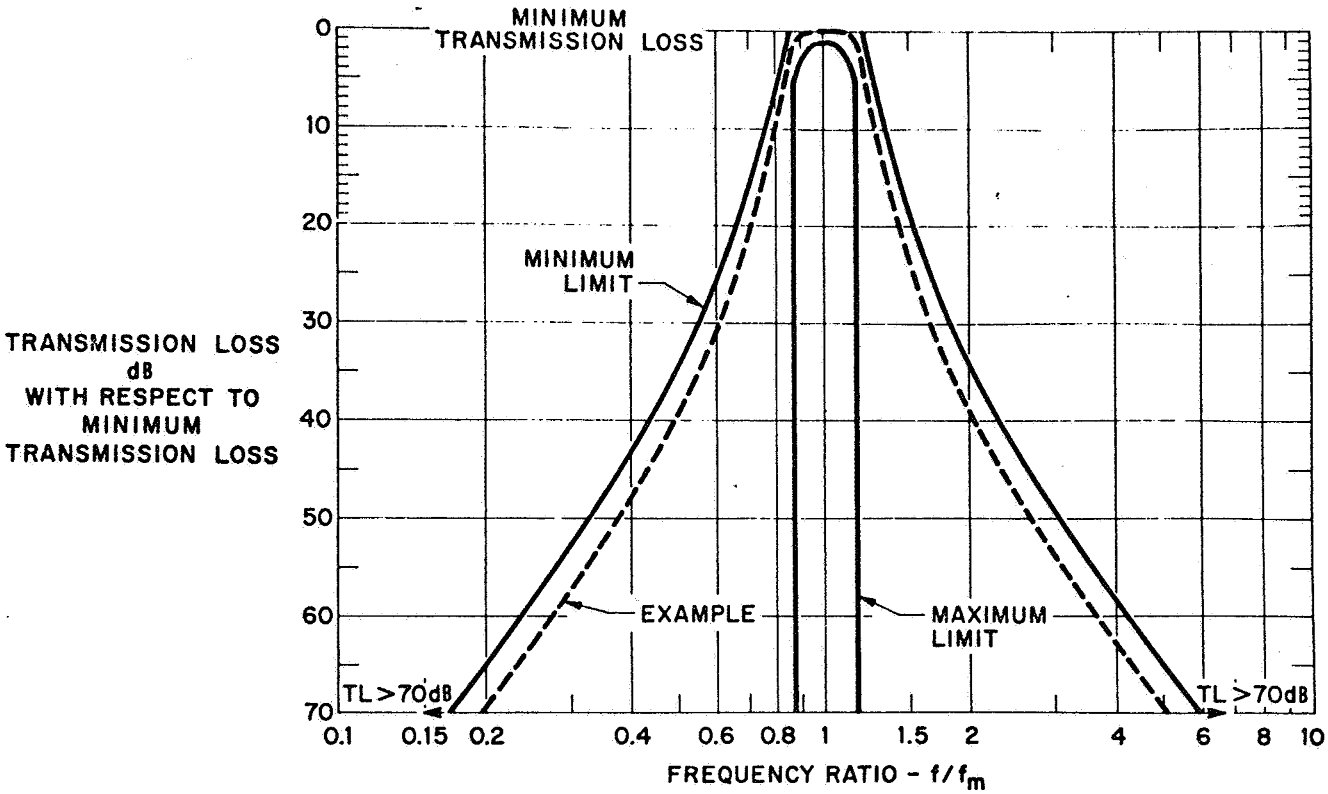


Fig. 4

Transmission Loss Limits — Half-Octave Band Filter, Class III

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

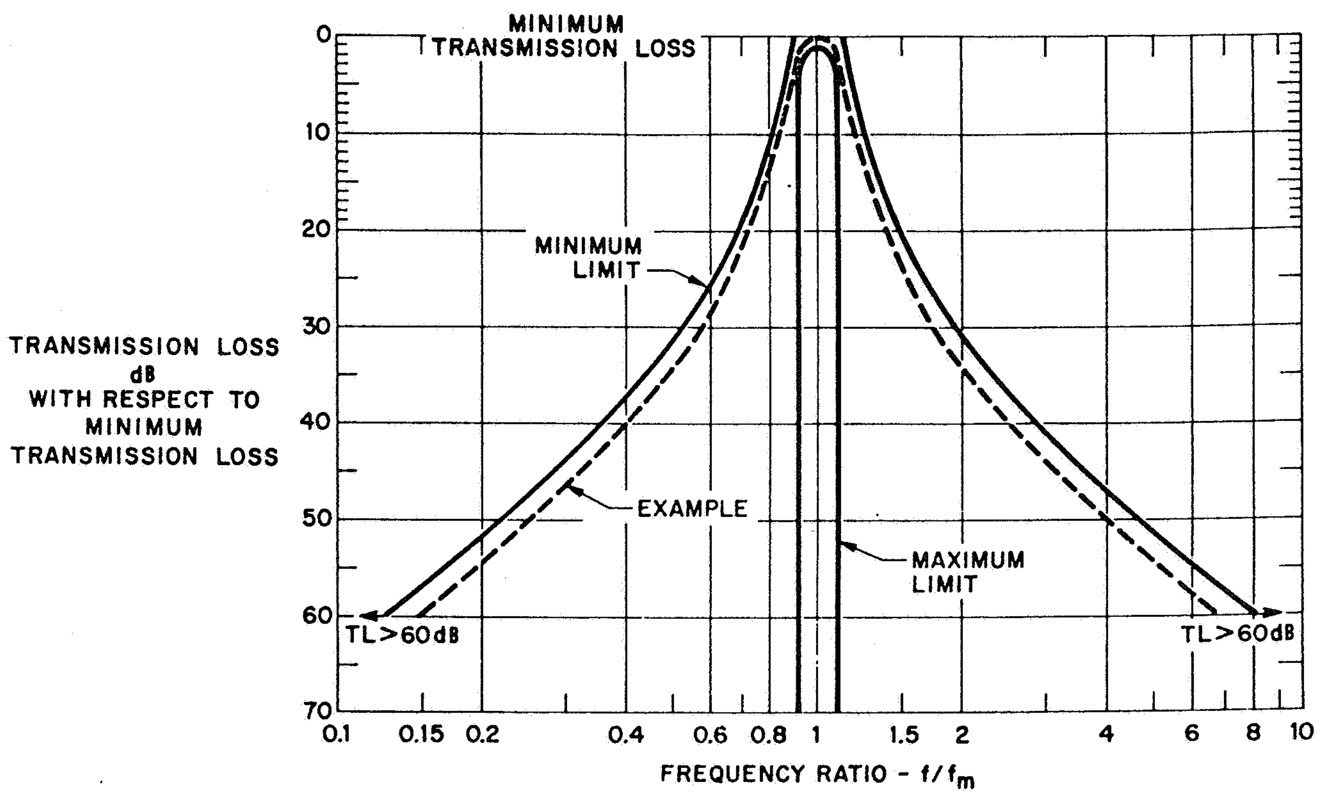


Fig. 5

Transmission Loss Limits — Third-Octave Band Filter, Class II

(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

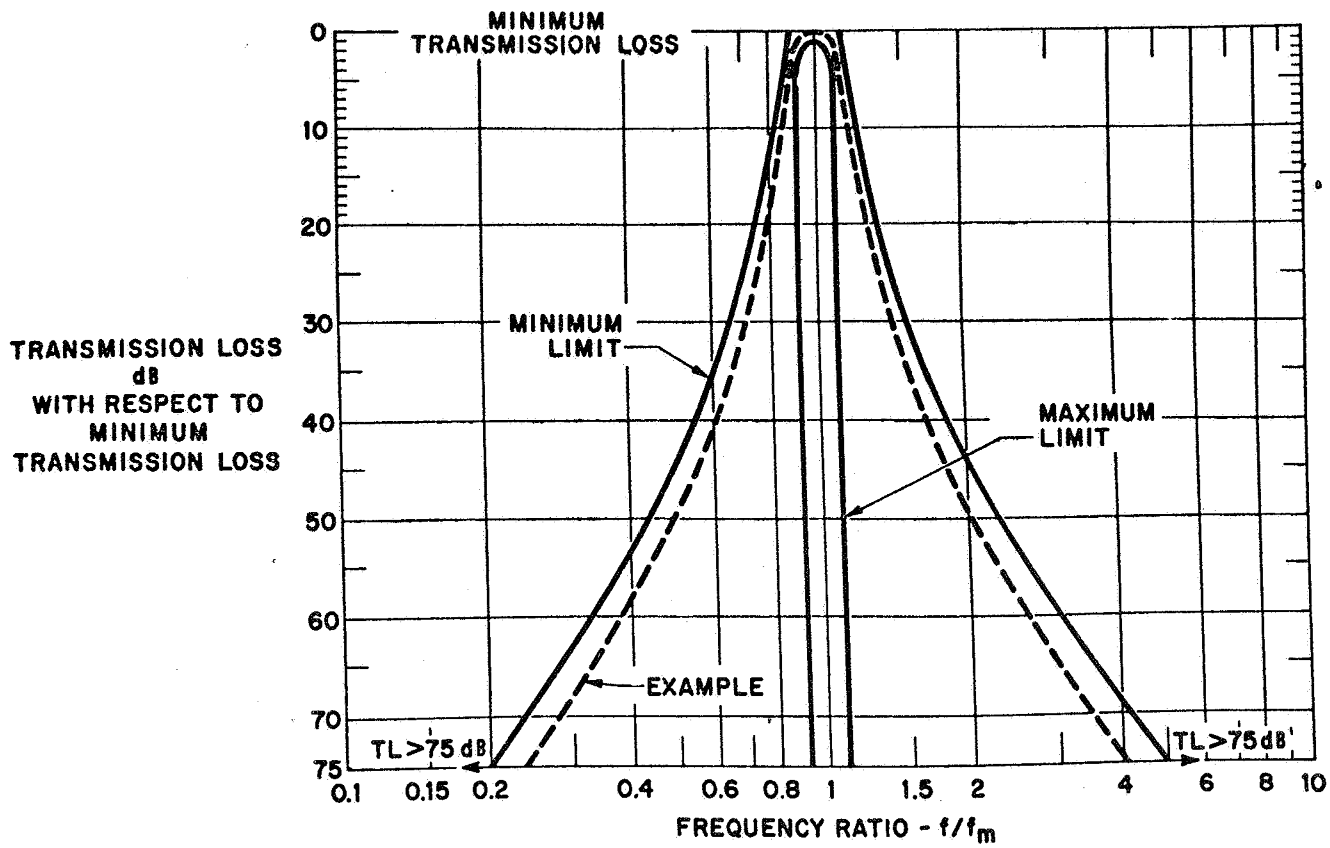


Fig. 6

Transmission Loss Limits — Third-Octave Band Filter, Class III
(Filter Characteristic Must Also Meet Requirements in 3.6 and 3.7)

3.5 Frequency Tolerance on Geometric Mean Frequency. For each band designated on the filter set in accordance with Table 1 of 3.1 or its extension, the geometric mean of the two frequencies where the transmission loss is 6 dB greater than the minimum transmission loss shall not depart by more than the tolerances shown in Table 4 from the designated preferred frequency nominal f_m calculated by the formulas of Table 2.

Table 4
Frequency Tolerances
on Geometric Mean Frequency, f_m

	Octave Bands	Half-Octave Bands	Third-Octave Bands
Tolerance	± 5%	± 3%	± 3%

3.6 Tolerance on Passband Uniformity. The peak-to-valley ripple in the transmission loss characteristic between the upper and lower nominal band-edge frequencies shall not exceed the values given in Table 5 for filters of the indicated bandwidths and classes.

3.7 Effective Bandwidth. For each filter band, the total integrated random white noise power (constant noise power per unit frequency) passed by the filter shall be within ±10 percent of that which would be passed by an ideal filter with flat passband between the nominal band-edge frequencies of 3.3 and infinite attenuation outside the passband. The white noise power passed by such an ideal filter is given by:

$$2^{-1/2} f_m P_m = 0.7071 f_m P_m \text{ for Octave bands}$$

$$(2^{1/4} - 2^{-1/4}) f_m P_m = 0.3483 f_m P_m \text{ for Half-Octave bands}$$

$$(2^{1/6} - 2^{-1/6}) f_m P_m = 0.2316 f_m P_m \text{ for Third-Octave bands}$$

where P_m is the noise power per unit frequency at the filter midband frequency f_m. The minimum transmission loss in the passband shall be used as the reference for calculating the effective bandwidth.

NOTE: See Appendix B for the nominal band-edge frequency transmission loss required to produce zero bandwidth error for Butterworth filters.

Table 5
Tolerance on Passband Uniformity

Filter Band	Filter Class	Maximum Allowable Peak-to-Valley Ripple dB
Octave	all	2
Half-Octave	II	1
	III	0.5
Third-Octave	II	1
	III	0.5